
BULB ONION PRODUCTION IN HAWAII

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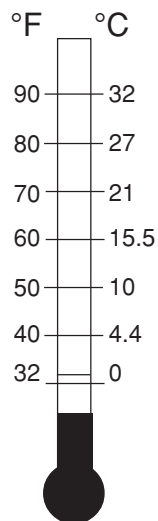
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Conversions from U.S. measure to metrics

In most cases, measurements in this book are given in the units most commonly used in the USA. For the convenience of other readers, the following conversions are provided.

1 inch = 25.4 mm = 2.54 cm
1 foot (ft) (12 inches) = 30 cm
1 pound (lb) = 0.454 kg
1 ounce (oz) = 28.4 g
1 acre = 0.4 hectare
1 lb/acre = 1.12 kg/ha

1 ton/acre = 2.24 tons/ha (2240 kg/ha)
1 gallon (gal) = 3.78 liters
1 square foot (sq ft) = 0.093 m²
1 gal/acre = 9.35 liters/ha
1 pound/square inch (psi) = 6.89 kPa
1 mile/hour (mph) = 1.6 km/hr

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Onions in Hawaii and around the world

Hector R. Valenzuela, Robin S. Shimabuku, Bernard A. Kratky, and Randall T. Hamasaki

Bulb onions (*Allium cepa* L. var. *cepa*) originated in southwest Asia and the Mediterranean region. Onions have been used as a condiment in the cuisines of ancient China, India, and Egypt for well over 4000 years. Although its main role in cooking is to provide flavor, onion is a significant source of vitamin C and potassium, contains about 60 calories in a medium-sized bulb, and has a very low sodium content. Onion and its relatives in the Amaryllidaceae family have long been used by many cultures for the treatment of various ailments, and modern science is beginning to reveal more potential health and medicinal benefits of these plants. Of particular interest is the traditional use of onion and garlic in many cultures to improve blood circulation, which may reduce the incidence of heart attack and strokes.

Onion relatives include shallots, scallions, rakkyo (rankyo), the green bunching onion, chives, and several species used as ornamentals. Scallions are bulb onions harvested when the bulbs are 1–2 inches in diameter, while the top-growth is still green and upright. At this growth stage, the bulb is mild and sweet and suited for use in green salads. Rakkyo is grown for its small bulbs for pickling. The growth habit of rakkyo is similar to shallots, but it has a different flavor.

Onion growth

The bulb onion is a shallow rooted, biennial plant that is grown as an annual. It has long, hollow leaves with widening, overlapping bases. The tubular leaf blades are flattened on the upper surface, and the stem of the plant also is flattened. Roots arise from the bottom of the growing bulb. Leaf initiation stops when the plant begins to bulb. The base of each leaf becomes one of the “scales” of the onion bulb, so the final bulb size depends in part on the number of leaves present at bulb initiation. The leaf base begins to function as a storage organ at bulb initiation, so the size of the leafy part of the plant also influences bulb size. Thus the more leaves present and the larger the size of the plant at the onset of bulb initia-

tion, the larger will be the bulbs and the greater will be the crop yield. Plants grown from large onion sets (small mature bulbs) bulb earlier than plants grown from smaller sets of the same age or from seed. The chronological sequence of crop maturity for the different types of onion propagules is (first) dry onion sets, (second) transplants from seed, and (last) direct-sown seed.

Night temperatures below 50°F for a 2–3 week period will induce bolting (seed stalk formation) in onions after the 7–10-leaf stage. However, little bolting occurs if temperatures are around 70°F. High temperatures during early growth also induce bolting.

Climate and daylength requirements for bulbing

Daylength and temperature influence bulb formation in onions. Also, before bulbing can occur, a certain amount of vegetative growth is required before the plant can respond to daylength. At a specific threshold, past the “juvenile” stage of leaf growth, the plant becomes sensitive to the bulbing stimulus that is triggered if the days are long enough.

When daylength is at or greater than the threshold for bulb initiation of the particular cultivar (cultivated variety) of onion being grown, bulbing occurs if the average daily temperature is 60°F or above and the average night temperature is 60–80°F. If the requirement for daylength is not met (that is, the days are not long enough when the onion plant is physiologically mature), leaf production continues without bulb formation. The bulbing response is stronger when nighttime temperatures are low, and also with larger plants.

Light intensity, light quality, and other factors interact with temperature and daylength to influence the bulbing response of onion cultivars. For example, with warm weather and bright days, onions bulb at shorter daylengths than when the days are cool and overcast. Excessive nitrogen applications near this time may delay the bulbing response, even if the critical daylength

period occurs at the right stage of crop growth.

Optimal temperatures for onions are in the range of 60–70°F during early growth and 70–80°F during bulb development. Once bulbing has been initiated, the growth of the bulb is influenced by temperature. Research indicates that onions maturing under hot conditions will have a lower dry matter content than those that mature under cooler conditions, and in general the lower the dry matter content—the fleshier the onion—the less pungent it is.

Onion cultivars are classified into groups based on the amount of daylength required to trigger bulb formation (Tables 1, 2). Although with respect to bulb formation onions are broadly classified as long-day plants, horticulturists distinguish groups of so-called short-day, intermediate-day, and long-day onion cultivars.

Short-day onions initiate bulbing when days are 12–13 hours long. These mild-fleshed onions, also called “European types,” have soft bulbs that are unsuitable for prolonged storage. They generally are grown below 35° latitude and are commonly grown in Hawaii. Short-day onions grown in the northern USA bulb very soon after planting and become little more than onion sets.

Intermediate-day onions have a 13.5–14 hour bulbing threshold. Like the short-day onions, they are relatively soft-fleshed and are grown for the fresh market. They are typically grown at 32–38° latitude. It is possible to grow intermediate-day cultivars with a daylength threshold between 13.5 and 13.8 hours in Hawaii. Plantings need to be properly timed so that the crop receives the appropriate daylength for bulbing.

Long-day onions require a daylength of 14.5 hours for bulbing. These “American” types are very pungent, with hard bulbs that store well. When long-day onions are grown in Hawaii, they produce only foliage.

To ensure a good crop, plant seeds at least 60 days before the daylength reaches the threshold required to trigger bulbing. Transplant seedlings at least 30 days before that date. Bulb ripening, indicated by the neck drying and the tops falling over, generally requires the same daylength or longer than that for bulb initiation, as well as temperatures in the range of 70–80°F and dry soil and atmosphere. Onion cultivars best adapted for growth in Hawaii initiate bulbs when days are 11.3–13.8 hours long, and they ripen at 13–13.8 hour daylengths.

Cultivars

Traditionally, production of mild (“sweet”) onions in Hawaii has been with short-day onion cultivars. Within the short-day group, there is a range of bulbing response to daylength. For example, although ‘Granex 33’ and ‘Texas Grano 1015’ are both short-day cultivars, the former is considered the shortest and the latter the longest of the group. To ensure bulb development, it is important to select the appropriate cultivar for the particular planting time. Failure to select a cultivar with an appropriate bulbing response to daylength can result in either premature or delayed bulbing. Table 1 is a general guide to onion cultivars suitable for Hawaii, based on trials of onion cultivars. However, variations in field

Table 1. Some bulb onion cultivars classified according to the daylength required for bulbing in Hawaii.

Short [‡]		Intermediate [‡]
<i>“Short”-short</i>	<i>“Medium”-short[*]</i>	
Granex 33	Chula Vista	Cimarron
Yellow Granex hyb.	Linda Vista	New Mex Yellow
Mercedes	Texas Grano 1015	Midstar
Rio Bravo	Evita	
Rio Zorro	DPS 1001	
Cougar		
Sweet Sunrise		
Jaguar		
Awahia (pungent)		
Monsoon		
Savannah Sweet		

[‡]Short-day cultivars are most commonly grown in Hawaii. “Short”-short-day cultivars are adapted to spring and fall planting; “medium”-short-day cultivars are planted in summer.

[‡]Intermediate-daylength cultivars that bulb when daylength is between 13.5 and 13.8 hours are also adapted for late spring planting (summer bulbing) in Hawaii. The cultivars listed were assessed in CTAHR trials on Molokai (elevation 375 ft), but they have not been tested elsewhere in Hawaii.

^{*}Within the “medium” short-day group, ‘Chula Vista’ and ‘Linda Vista’ have the shortest daylength requirement, while ‘Texas Grano 1015’ has the longest.

Table 2. Daylength periods, including civil twilight, for the Hawaii latitude 21°N.

Daylength (hours)	Period	Duration of period (days)
11.3 – 12	Jan. 1 – Feb. 24	55
12 – 13	Feb. 24 – Apr. 15	50
13 – 13.5	Apr. 16 – May 13	28
13.5 – 13.8 – 13.5	May 14 – Aug. 1	80
13.5 – 13	Aug. 2 – Aug. 31	30
13 – 12	Sept. 1 – Oct. 18	48
12 – 11.3	Oct. 19 – Dec. 31	75
Shortest day	11 hours, 16 minutes (Dec. 22)	
Longest day	13 hours, 50 minutes (June 22)	

(from Nakagawa 1957)

management practices and climate conditions also affect a cultivar's bulbing response to daylength. Little work has been done in Hawaii to test intermediate-daylength onion cultivars, but some of them can be planted in the spring to produce bulbs during Hawaii's longest days. Selecting among this group for cultivars adapted for summer production in Hawaii may reveal useful new cultivars to meet particular market demands.

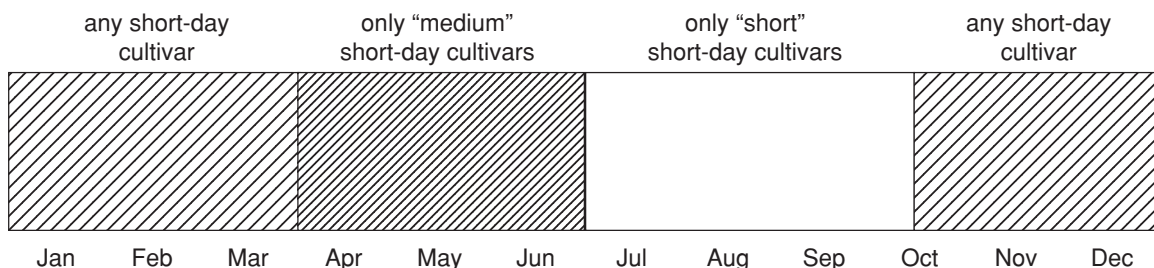
The short-day, mild-fleshed bulb onions currently grown in Hawaii include 'Granex 33' (late maturing), 'Yellow Granex' hybrid (early maturing, deep-flat shape), and 'Texas Grano 1015' (large, round globe). Cultivars formerly grown in Hawaii include 'Early Texas Grano 502' (top-shaped, matures later than 'Yellow Granex'), 'Grano 429', and 'Excel'. All of these produce the "Maui" sweet onion when grown under the growing conditions of Kula, Maui. A pungent short-day onion cultivar developed by CTAHR's Department of Horticulture is 'Awahia', which is grown in home gardens but is not grown commercially in Hawaii. Another pungent cultivar tested in Hawaii is 'Red Creole'.

Short-day cultivars grown in other U.S. locations include 'Savannah Sweet' (Granex type), 'Sunex 1502', 'Henry's Special' (flattened globe, slightly top-shaped), and 'Sweet Dixie' in Florida; 'Rio Hondo', 'Gold Express', and 'Gran Prix' (Imperial Valley "sweets"); and 'Early Supreme'. The popular Georgia-grown "Vidalia" sweet onions are defined by the Federal Register as onion cultivars "of the hybrid Yellow Granex, Granex parentage, or any other similar cultivar recommended by the Vidalia Onion Committee." Cultivars that fall under this category include 'Dessex', 'Granex 33', 'Granex 429', 'Rio Bravo', 'Sweet Georgia', 'Sweet Vidalia', and 'Savannah Sweet'. 'Sugar Queen' is a Vidalia-grown onion with rapid growth and early maturity. Cultivars not classified as Vidalias that do well in Georgia include red and white Granex types, Texas Grano types (502, 1015, 1025), and some other short-day cultivars.

Short-day, white-skinned onion cultivars grown in other locations include 'Eclipse' in Florida; 'White Supreme', 'Reina Blanca', and 'Contessa' (deep-globed, trim-necked, early cultivars) grown in the Imperial Valley of California; 'White Granex' and 'Texas Early White', globe-shaped cultivars grown in Texas; and 'White Tampico' grown in Central America. Short-day, red-skinned onion cultivars grown in other locations include 'Red Creole C-5' (pungent, Florida); 'Red Grano', 'Rio Raja', and 'Rojo' (Imperial Valley); and 'Red Granex' (Texas).

Cultivar selection also depends on intended use. For example, bulbs with single centers and thick, succulent rings are desirable for the fried-onion-ring market.

Onion cultivar trials have been conducted recently in several locations in Hawaii including Waianae, Waimanalo, and Kunia on Oahu; Kula on Maui; Pulehu on Hawaii; and on Molokai. Results from these trials are considered preliminary because cultivar recommen-

Figure 1. Generalized calendar for planting short-day bulb onion cultivars in Hawaii.

See Table 1 for cultivars in the categories mentioned. Cultivar response to daylength may vary with location and growing practices.

dations can be made only from multi-year experiments. Based on the research conducted to date, promising cultivars for spring planting in Kula, Maui, include ‘Mercedes’ (round), ‘Mr. Max’ (round), ‘Rio Bravo’ (flat), ‘Monsoon’ (open-pollinated, round, yellow), and ‘Savannah Sweet’. Promising cultivars for fall planting in Kula include ‘Chula Vista’ (round, yellow, maturing a little earlier than ‘Linda Vista’), ‘Linda Vista’ (round, yellow), ‘Evita’ (round), ‘Rio Selecto’, and ‘Sweet Sunrise’. Promising cultivars for fall planting in Kunia, Oahu, include ‘Sweet Dixie’, ‘Rio Bravo’, ‘Rio Zorro’, and ‘Sunex-1502’.

Bulb onion production areas in Hawaii

The cultivars listed in Table 1 can be grown throughout the state. With the proper cultivar, direct-seeded and transplanted onion production can be successful in Hawaii year round. Planting of onion sets can also extend the harvest season into the summer months.

Sweet onions have traditionally been grown in Hawaii at Kula, Maui, which has a desirable combination of climate, soil type, and elevation (>1000 ft). Experienced farmers have developed a market reputation and an export industry growing the popular “Maui sweet onion,” which sells for a premium price. The “sweetness” of bulb onions grown in other parts of the state depends on the onion cultivar, soil quality (especially sulfur levels), elevation, time of the year grown, and cultural practices.

Soils and soil fertility management for onion production

Hector R. Valenzuela and Bernard A. Kratky

Choosing a soil to grow onions

Onions require a soil that has good drainage. The best soils for onions are medium-textured sandy loams high in organic matter. In light, sandy soils (such as are found in Florida) onions mature earlier and have been observed to cure and store better than those grown in heavier soils. In heavy soils with high clay content, onions may develop misshapen bulbs, especially with close plant spacing.

Soils for onion production should have low salinity. Significant onion growth reduction occurs at soil salinity levels of 1.4 dS/m (= mmho/cm = mS/cm) or greater.

A soil in which onions are to be planted should preferably be relatively free of weeds.

Amending the soil

Organic soil amendments such as manure and compost can improve soil structure, moisture-holding capacity, and fertility. Additions of organic matter can also positively affect the density and quality of onion bulbs. Poultry manure at 1–2 tons/acre either alone or in combination with synthetic fertilizer has been shown to produce acceptable yields of marketable onions.

The recommended soil pH for onions in Hawaii is between 6.0 and 6.8. Soils that are either below this range (too acidic) or above it (too alkaline) may result in delayed growth and poor yield. To raise the pH of an acid soil, apply a liming material (dolomite or agricultural lime) according to soil test recommendations. The liming material must be applied two to three months before planting and should be thoroughly mixed into the upper 6 inches of the soil by cultivation. It has been a common practice in Hawaii to apply 1 ton/acre of agricultural lime to an acid soil, but such a general “rule of thumb” is not always practical and may not be economical. The correct amount varies with the particular soil type, its pH, and its buffer strength (resistance to change in pH). Have the soil tested and follow the liming recommen-

dations. For detailed information, see the CTAHR publication AS-1, *Liming acid soils of Hawaii*. (Also, see Land and bed preparation, p. 15.)

Managing soil nutrient levels

The identification and correction of nutrient deficiencies or toxicities are essential for good crop management, which in turn can contribute to higher economic returns. Among the consequences of applying too much or the wrong kinds of fertilizer are

- plant toxicity and reduced growth and yield
- excessive foliage growth resulting in greater incidence of plant disease and insect pest damage
- groundwater contamination
- economic losses due to wasted fertilizer.

Failing to correct soil problems or to apply enough of the right types of fertilizer can result in poor yields and wasted effort. Soil and plant tissue analyses are key tools used to prevent, diagnose, and correct crop fertility problems. These analyses and recommendations based on them for liming and fertilizer applications can be obtained from the CTAHR Agricultural Diagnostic Service Center or commercial laboratories that use data calibrated for Hawaii’s soils and crops.

Soil analysis

A basic soil analysis provides information on two important soil characteristics: soil pH, and the levels of available nutrients. Other specialized analyses can provide information on the levels of soil salinity, organic carbon, aluminum, nitrogen, and micronutrients. The soil sample to be tested should be a composite of five to ten subsamples of uniform size taken from each distinct soil area to be cropped. In conventionally tilled fields, sample from the top 8 inches of soil. The subsamples, which

may be “cores” collected with a soil sampling auger or uniform sized samples taken with a spade, should be well mixed together in a clean container. After mixing, a sample for analysis consisting of at least 1 pint of soil should be placed in a clean plastic bag, labeled, and sent to the laboratory. It is helpful to identify the name of the soil series, which is available from soil maps, and provide this information with the soil sample. For more information, see *Testing your soil, why and how to take a soil-test sample*, CTAHR publication AS-4.

Plant tissue analysis

Plant tissue analysis is done to monitor the nutrient levels in plant tissues. It is most useful in combination with soil analysis data and records of past fertilizer applications and crop performance. Plant tissue analysis measures the elements in the “index tissue,” a particular plant part determined by experimentation to be the most reliable indicator of the plant’s nutrient status. The analysis results are compared with sufficiency ranges (standards) established for the particular crop (Table 3). The target levels for particular nutrients are those levels that will result in at least 95 percent of the maximum yield of a crop in a particular location. The “sufficiency” range for a nutrient comprises the values between the deficiency and excess levels. The “critical level” for a nutrient is at the midpoint of its sufficiency range. Below the critical level, the crop may suffer deficiency of that nutrient. Above the critical level, adequate growth can be expected, as far as that particular nutrient is concerned. When levels of a nutrient are in excess (above the sufficiency range), nutrient imbalances can occur, and the plants may become prone to diseases or physiological disorders.

It should be noted that research to calibrate soil fertility levels, onion tissue nutrient levels, and crop yields has not been conducted in Hawaii. The data used here were borrowed from work conducted with other crops or with onion in other locations.

Collecting the plant tissue sample

Sampling is often the weakest step in the tissue testing process. If the samples collected are not representative of the entire crop, are not from the correct part of the plant, or are not collected at the right stage of crop growth, the analysis results can be misleading.

The sample must be large enough to accurately rep-

Table 3. Plant tissue nutrient sufficiency ranges for bulb onion.

Plant part to sample: recently matured leaves (20–25 leaves)
Crop stage to sample: just before bulbing

Macronutrients (%)			
N	2.0	–	3.0
P	0.2	–	0.5
K	1.5	–	3.0
Ca	0.6	–	0.8
Mg	0.15	–	0.3
S	0.2	–	0.6
Micronutrients (ppm)			
Fe	50	–	100
Zn	15	–	20
Mn	10	–	20
Cu	5	–	10
B	10	–	25 (toxic = >100)

Source: D.N. Maynard et al., 1999, *Onion, leek, and chive production in Florida*; see references. Data for Mn, Cu, and Zn can be erratic when fungicides containing these elements are used.

resent the overall population of plants in the field. Leaves collected must be clean, without contamination by soil, dust, fertilizer, or pesticide. Avoid collecting from plants that are damaged by insects, mechanically injured, or diseased, unless these are typical of the crop being sampled. Sampling is not recommended when plants are under moisture or temperature stress. After sampling, take care that the sample is not contaminated or exposed to heat before analysis. Under hot field conditions, place plant tissue samples in clean plastic bags in an insulated cooler.

For onion plant tissue analysis, collect a sample consisting of the most recently matured leaf from 20–25 plants. The tissue samples should be collected when the crop is just beginning bulbing. For best results, be consistent from crop to crop with the growth stage sampled.

Some fungicides contain the elements copper, zinc, or manganese, and as a consequence, tissue analysis from plants sprayed with these fungicides will have falsely high values for these micronutrients.

Fertilizer applications

Nutrients removed in the bulbs of a dry-bulb onion crop yielding 40,000 lb/acre are (in lb/acre) 102 N, 17 P, 93 K, 20 Ca, 11 Mg, 7 Na, 0.01 Zn, 0.3 Mn, 0.8 Fe, 0.02 Cu, and 0.1 B. The tops, in this case, would remove about 35 N, 5 P, and 45 K.

Fertilizer applications near the shoot may cause damage to onion plants. To avoid fertilizer burn during dry periods, irrigation may be necessary to move the nutrients into the soil. Onions are shallow feeders—most onion roots are found in a 6-inch radius from the stem. To reach this compact root system, apply fertilizer before planting in a broad band 2.5–3.5 inches below the seeded or transplanted row.

“Starter” fertilizers may help to improve stand establishment and promote early yields, even in well fertilized fields. Research has found that an ammonium phosphate starter solution placed below onion seeds at sowing resulted in faster seedling growth and earlier maturation (1–3 days), although crop yield was not affected. Starter fertilizers may be especially beneficial when seedlings or young transplants are exposed to stressful growing conditions.

Nitrogen (N)

To compensate for the long growing season and the potential for nutrients to be lost by leaching due to rainfall or irrigation (see Irrigation, p. 17), apply N (with K, if needed) several times during the growth period. About 75 percent of the N uptake takes place after bulbing begins. Deficient amounts of available N result in early bulb maturity and reduced bulb size. High N levels, although they increase bulb size, may—if excessive—cause large necks, doubles (Figure 2), increased pungency, and soft bulbs with poor storage quality.

A generalized fertilizer schedule for nitrogen is to apply 50 lb N/acre before planting, side-dress seedlings with 50 lb/acre N at $\frac{1}{3}$ maturity (about the five-leaf stage), and apply 50 lb/acre at $\frac{1}{2}$ maturity, for a total of 150 lb/acre per crop. Alternatively, after the pre-plant application, split the remaining fertilizer into equal amounts applied at monthly intervals up until $\frac{1}{2}$ maturity (about the seven-leaf stage). Fertigation can also be used to apply soluble N fertilizers. Be sure to observe regulations for fertigation, such as the requirement for back-flow preventers. Late-season N applications can be in the form of calcium nitrate, especially when plant tissue analysis indicates a need for additional calcium.

Phosphorus (P)

Phosphorus availability is especially important during the first half of the crop growth cycle, and P is usually applied before planting if the need is indicated by soil analysis. To amend the P status of the soil, P fertilizer

must be thoroughly mixed with the soil in the onion root zone before planting. Applications of P fertilizer to the soil surface in Hawaii generally will not move into the root zone without cultivation.

Hawaii soils vary a great deal in their ability to retain and release P. Soil clay particles retain P by *adsorption* (accumulation on their surfaces), and depending on the type of clay, the soil may hold on to this adsorbed P very strongly. Some soils can adsorb large amounts of P, and for good crop growth on these soils you must add more than enough phosphate fertilizer to satisfy their P-adsorption capacity before any of the P applied becomes available to plants. Contact your local Cooperative Extension Service agent or the CTAHR Agricultural Diagnostic Service Center for assistance in determining the recommended P fertilizer application rate for your soil. For detailed information, read CTAHR publication AS-2, *Predicting phosphorus requirements of some Hawaii soils*. In general, when soil analysis indicates low P, incorporate 300 lb/acre of treble superphosphate (0-45-0) or its equivalent in a banded application. The band should be 2½–3½ inches below and to both sides of the row before the onions are planted. Banded applications limit the exposure of the fertilizer to soil particle surfaces and create a P-rich zone from which the onion plants can take up P without “competition” from the soil’s adsorption capacity.

When the level of available P in soil is below 30 ppm (Modified Truog extraction method), onions are likely to benefit from symbiotic associations with mycorrhizal fungi such as *Glomus* species. These soil fungi attach themselves to onion roots and extend their filaments (hyphae) into the adjacent soil, thereby improving plant growth by absorbing more of the available P in the soil. Under “organic farming” conditions, grow-

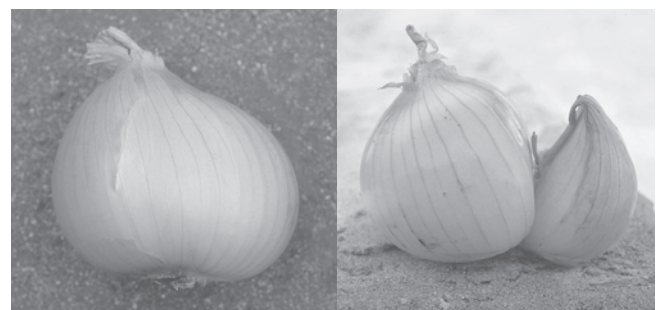


Figure 2. A “double” (left) will result in a “split” (right). These malformations can result from excessive nitrogen application during vegetative growth or excessive soil moisture during bulb ripening.

ers may choose not to apply certain forms of phosphate, such as superphosphate and treble superphosphate, that have been treated with acid to increase P solubility. P sources suited to these farming systems, such as rock phosphate, release P very slowly and only under acidic conditions, and hence the P they contain does not readily become available to plants in sufficient quantity. Under such conditions, and especially when soil P levels are low, association with mycorrhizal fungi may become significant in affecting crop growth and yield.

Potassium (K)

Onions are fairly susceptible to K deficiency. For soils low in K, apply muriate of potash (0-0-61) at 300–350 lb/acre (11–13 oz/100 sq ft). Apply half of this amount at planting and the remainder four to six weeks later along with a scheduled side-dressed N application.

Calcium (Ca)

Calcium improves the tissue integrity of the onion bulbs and increases their postharvest shelf life. Commonly used calcium sources include calcium carbonate, dolomitic limestone, gypsum, and calcium nitrate. Calcium carbonate and dolomitic limestone are liming materials that should be incorporated into the soil before planting. Sufficient moisture and time should be provided for their activity. Gypsum (calcium sulfate) is a Ca source that can be used where a liming effect is not desirable—such as when the soil pH is high but the soil calcium level is low. Gypsum typically contains about 18% sulfur, and this added S might increase the crop's pungency. Calcium nitrate is a fast acting source of Ca (21%) and N (15%).

Magnesium (Mg)

Dolomitic limestone (dolomite) and magnesium sulfate (epsom salt) are two commonly used sources of magnesium. Dolomitic limestone may be incorporated into the soil before planting to provide Mg and reduce soil acidity. Magnesium sulfate (epsom salt, 11–16% Mg) can be applied before planting, sidedressed or fertigated. Magnesium sulfate contains 22–24% sulfur, the addition of which might increase bulb pungency. Magnesium sulfate can also be applied as a foliar spray using 10 lb/acre magnesium sulfate in 100 gallons of water.

Sulfur (S) and pungency

Sulfur is an essential element required by onions to achieve optimum development. On soils low in S, its application can increase yields, as illustrated by research in Texas where S applied at 6 lb/acre increased onion yield by 10 percent over the yield at 2 lb/acre S. On the other hand, high levels of S can contribute to increased pungency in onions, which may be undesirable if the intent is to produce mild-flavored onions. Because many fertilizers contain S, a fertilizer application program can contribute to soil S buildup. To minimize this on soils where S may contribute to undesired pungency, S and sulfate (SO₄) in fertilizer formulations should be budgeted to limit applications of the element to 45 lb/acre up to bulbing, and S should not be applied after bulbing begins. Examples of sulfur-containing materials include ammonium sulfate (24% S), potassium sulfate (18% S), magnesium sulfate (22–24% S), potassium-magnesium sulfate (22% S), normal superphosphate (12% S), and gypsum (16–18% S). In Central America, sweet onions for export are not grown on soils that have sulfur levels above 18 ppm.

The compound responsible for onion's flavor and pungency is the sulfur-containing allyl propyl disulfide. The pungency of onions appears to be correlated with dry matter (DM) concentration. The major carbohydrates that contribute to "sweetness" in onions include sucrose, fructose, and glucose. In low-DM cultivars (below 8 percent DM) these sugars result in a "sweet" taste perception. As DM content increases to about 16 percent, fructans accumulate. Since fructans provide more of a "starchy" taste, comparable to that of potatoes, the higher DM content leads to a less "sweet" tasting onion. Thus it is the proportion of the various sugars occurring in different onion cultivars that determines the "sweetness," rather than the total sugar content as measured by a refractometer. For this reason, the term "sweet" is really a misnomer—"mild" is the correct description for onions with low pungency.

Higher growing temperatures increase pungency. Twice as much pungency may be expected when the temperature at bulbing is 90°F than when it is 50°F. This increase may be due to increased sulfur uptake caused by high temperature.

Pungency also increases under dry growth conditions. Adequate soil moisture can contribute to lower dry matter content, diluting concentrations of flavor precursors and resulting in a milder onion.

High nitrogen application levels may result in higher pungency, although sulfur is the most significant contributing factor in pungency. The onion variety used and the crop maturity at harvest also affect pungency, but to a lesser degree than sulfur.

Micronutrients

In soils with very low micronutrient levels, annual applications of (lb/acre) 5 Mn, 3 Zn, 4 Fe, 3 Cu, and 1 B are recommended. When Zn deficiencies are observed, spray plants with 1 lb/acre Zn in 50–100 gallons of water.

Nutrient deficiency and toxicity symptoms

Onion growers can minimize the occurrence of nutrient deficiencies and toxicities by following fertilizer recommendations based on soil and plant tissue analyses and by keeping careful records of annual fertilizer inputs.

Deficiency symptoms

Nitrogen (N)

- leaves light green
- older leaves die, showing bleached yellow color
- leaves are short and small in diameter
- growth stiff and upright

Phosphorus (P)

- older leaves wilt
- tips die back
- green areas are mottled
- dead leaves turn black
- slow growth, delayed maturity, “thick necks”

Potassium (K)

- older leaves first show slight yellowing
- leaves then wilt and die, appearing crinkled like crepe paper
- dying and drying begin at tips of older leaves
- poor bulb formation
- lower yields, soft bulbs with thin skins, delayed maturity

Calcium (Ca)

- tips of younger leaves die back
- may show dry or brown tissue in bulb
- leaves appear limp
- root injury may be evident

Magnesium (Mg)

- older leaves die back from the tips
- foliage dies prematurely
- growth is slow

Sulfur (S)

- fewer leaves produced
- new leaves are uniformly yellowed

Iron (Fe)—similar to calcium except no root injury is evident

Zinc (Zn)—onions are sensitive to zinc deficiency

- tips of leaves die back
- slow growth and stunting
- corkscrewing of leaves, or an outward bending of leaves
- deficiencies observed especially at soil pH above 6.5

Copper (Cu)

- bulbs lack solidity
- bulb scales are thin and pale colored
- leaves are chlorotic
- deficiencies occur especially in organic soils

Manganese (Mn)

- leaf curling
- slow growth, delayed bulbing, thick necks, stunted growth, poor production
- deficiencies occur in strongly alkaline soils

Boron (B)

- leaves are deep blue green
- youngest leaves become mottled yellow and green with distorted, shrunken areas
- basal leaves become very stiff and brittle, ladderlike cracks appear on upper sides

Molybdenum (Mo)—deficiency is rare

- leaves light green, similar to nitrogen deficiency
- wilting and dying of leaf tips
- dieback of older leaves
- bleached yellow color

Toxicity symptoms

Salinity

- dull leaf color and tipburn due to water stress
- elevated tissue analysis levels of sodium (Na) and chlorine (Cl)

Chlorine (Cl)

- chlorosis
- tip burn
- stunting

Figure 3. Onion growth and field management schedule.

[illegible]

Drawing from M.P. Hoffmann et al. (1996) (see References); used with permission.

Culture and management practices

Hector R. Valenzuela and Bernard A. Kratky

In Hawaii, sweet onions are commonly grown in bare-soil culture with irrigation by drip lines or portable sprinklers. Growing onions under plastic or organic mulch with drip irrigation may result in improved weed control and efficiency in the use of fertilizer and water. Onions may also be grown under solid-covered greenhouses in high-rainfall areas.

Land and bed preparation

Thorough and timely soil preparation is necessary to obtain good crop stands and effective weed control. Rotary-mow and disc crop residues from the previous planting as soon as possible. At least four weeks before planting, plow to a depth of at least 10 inches, burying undecomposed residues. Apply pre-plant fertilizers and soil amendments and incorporate them with a harrow or rotovator. Frequent light disking may be necessary for weed control before planting.

Onions may be direct-seeded or transplanted. If onions are to be direct-seeded, work the soil to a fine texture to ensure good seed germination. In production areas that rely primarily on herbicides for weed control, onions are planted in beds with four to eight narrowly spaced rows per bed. Raised beds 6–8 inches high will help to improve water drainage in poorly drained soils or during rainy periods, such as the winter months. To follow a “stale-bed” technique (see Weeds, p. 38), prepare beds at least six weeks before planting. Bed width and final plant spacing vary depending on the desired bulb size, cultivar used, time of year (winter vs. summer plantings), and equipment available for bed or row preparation, cultivation, and spraying the crop. Bedding disks and a press can be used to prepare raised, compacted, flat-topped beds. A firm bed resulting from rainfall or irrigation is especially important to establish a uniform seeding depth when direct-seeding. If direct-seeding, apply a preemergence herbicide immediately after planting, and irrigate by overhead sprinkler to obtain adequate weed control.

Research with sweet onions in Florida has shown yield benefits with the use of both white plastic mulch during warm growing conditions and black plastic during spring plantings. Rice-straw mulch is used in many Asian countries. In Michigan, residues of cover crops such as barley are used as mulch. Organic mulches maintain cool temperatures in the beds, help to conserve moisture, prevent erosion, and provide some weed control. However, if the organic mulch retains excessive moisture, the onions may rot at harvest time. Cover crops or green manure crops grown in rotation with onions may provide benefits to an onion production program including improved field drainage and soil tilth, weed control, reduced nematode and soil-borne pathogen populations, and cycling of soil nutrients from lower in the soil profile. In New York state, several growers have adopted the practice of planting 20 percent of their onion fields in a Sudan grass rotation, resulting in increased yields and 15–30 percent increased return from the subsequent onion plantings.

Planting

In Hawaii, most short-day onion cultivars can be planted during the months of October through March. The so-called “medium”-short-day cultivars can be planted during April through June. The so-called “short”-short-day cultivars can be planted during July through September. See Table 1 (p. 6) for names of cultivars and Figure 1 (p. 7) for a suggested planting schedule for the different daylength-sensitivity groups under Hawaii’s conditions.

For production of sets, seeds are generally sown during April through June, and sets are harvested about 6–8 weeks later for planting during the rest of the summer and early fall. Shallots and rakkyo from sprouting bulbs are planted from November to February. Single bulbs will divide into several tillers that bulb in June–July followed by dieback of the tops in August–September.

Direct-seeding

Onion seed germination occurs at temperatures between 50° and 95°F, but the optimum is 75°F. After direct-seeding bulb onions, timely irrigation and adequate weed control are required. Direct-seeding may be preferable to transplanting for bulb onions in large-scale operations when plant populations are greater than 120,000 plants/acre.

Precision seeding, applicable for direct-seeded dry onion production, results in increased size uniformity and fewer culls. Seed pelleted with a fungicide-impregnated coating is available for use with precision planters. Coated seed is recommended if using Stan Hay, Beck, or Graymore planters, but not if using vacuum planters. Research in England found that priming onion seeds may be beneficial to enhance stand establishment and seedling growth, especially if seedlings experience stressful growing conditions, although yields were not affected by seed priming. Seed priming is a physiologically based treatment to enhance germination. Primed seeds can be purchased from various commercial sources. Primed seed should be planted during the season for which it was primed. Otherwise, the seed should be retested before planting to assess its germination rate.

Onion seed is short-lived, retaining viability for only two years or less. Seed count for onions is about 9500 seeds per ounce. The amount of seed required for a crop of bulb onions is 1 lb/acre for transplanting or, for direct seeding, 4–5 lb/acre ($\frac{1}{2}$ oz per 100 ft of row) of seed or 20–30 lb/acre of coated seed. For direct-seeded green onions, about 12–18 lb/acre of seed is required (3–4 oz per 100 ft of row).

Bulb onions are commonly planted at a density of two to three plants per square foot. Typical plant spacing for onions in Hawaii is given in Table 4. In other onion producing areas, bulb onions are grown on raised beds. One such system uses raised beds 4–8 inches high and 16 inches wide, with beds spaced at 36 inches from center to center. Two rows of onions, spaced about 6 inches apart, are planted on each bed, with 4–6 inches between plants in the rows, resulting in planting density of 65,000 to 100,000 plants/acre. In Texas, standard spacing is 2–4 inches between plants in the row, with from two to four rows on beds 38–40 inches wide, or with five to seven rows on raised beds 80 inches wide. In Oregon, dry onions are planted with 3–4 inches between plants in the row and 15–24 inches between rows, resulting in a planting density of 120,000 to 140,000 per acre. In greenhouse trials at CTAHR's research station

Table 4. Plant spacing for onions in Hawaii.

Onion type	Spacing (inches) between	
	Rows	Plants
Bulb onion in field rows	15 – 24	3 – 6
Bulb onion in beds	8 – 12	6 – 9
Non-multiplying green onion	12 – 20	$\frac{1}{3}$ – $\frac{3}{4}$
Multiplying green onion	12 – 20	8 – 10
Shallots	12 – 16	8 – 12
Futo-Negi	15 – 30	3 – 4

Source: Fukuda 1990.

in Volcano, Hawaii, Granex onions have been transplanted into 4-row beds with rows 9 inches apart and within-row spacing of 6 inches.

Onion seeds are planted at a depth of $\frac{1}{4}$ – $\frac{3}{4}$ inch, with the shallower depths for heavier soils. Sets are planted 1–1½ inches deep. Shallower planting may result in flatter bulbs, while deeper planting may result in taller, top-shaped bulbs. Adequate moisture must be provided when planting deeper than $\frac{3}{4}$ inch to develop fuller bulbs, because uneven watering during bulbing will result in misshapen bulbs.

Transplants

Sweet onions are generally grown in field nurseries, and 1–2-month-old seedlings are then transplanted into the production fields. The advantages of transplanting onions compared to direct-seeding include

- 6–10 weeks less time spent in the production field
- better plant stands
- transplanted seedlings compete better against weeds
- less water used for irrigation
- less pesticide used during the shorter growing season
- less “sand-blasting” of seedlings in areas that experience windy conditions
- less erosion and nutrient leaching.

However, transplanting operations may become expensive due to their high labor requirement in large-scale operations or when plant populations are greater than 120,000 plants/acre. Also, a seedling facility and supplies are needed to grow seedlings.

Nursery seedbeds to grow transplants should have good drainage and excellent soil texture and be free of roots or clods. An acre of nursery onions is needed to

establish 10 acres of bulb onions. To establish seedlings in a field nursery for 1 acre of bulb onions, sow 2 lb of seed in a 4500 square foot seedbed (a per-acre rate of 20–30 lb). Seeds may be broadcast, but they usually are planted in rows 6–8 inches apart and $\frac{1}{4}$ – $\frac{3}{4}$ inch deep at a rate of 60–70 seeds per linear foot. Four to six rows can be established in 72-inch beds. Adequate stands can be obtained using Planet Jr. planters or similar implements. Weekly fungicide treatments may be necessary under conditions conducive to disease development. Apply fertilizer at 2, 4, and 6 weeks after sowing. Depending on the time of the year, seedlings will be ready for transplanting 4–10 weeks after sowing, when seedlings necks are pencil size ($\frac{1}{4}$ – $\frac{5}{16}$ inch diameter), are 7–12 inches tall, and have three to five leaves. Reduce the water supply about 7–10 days before transplanting to harden the seedlings. After pulling the seedlings, clip the roots to 1 inch and the tops to about 4 inches immediately before transplanting. Onions can be hand-transplanted, but mechanical transplanters are also available for large-scale operations. In some areas, growers cultivate shallowly after transplanting to throw soil over the plants. Irrigate immediately after transplanting.

Growing seedlings in 200-cell plastic trays is the preferred method in CTAHR research trials, because it results in minimal transplant shock. Research in Michigan with these trays showed that optimal Spanish onion yields were obtained by growing two seedlings per cell for 8–12 weeks and providing the seedlings with a weekly nutrient solution containing 150–225 ppm N, 322 ppm P, and 62 ppm K.

Sets

Bulb sets, small bulbs about $\frac{1}{2}$ – $\frac{3}{4}$ inch in diameter, are sometimes used for planting onions during the late summer through fall (August through October). The so-called “short”-short-day varieties can be grown by sets (see Table 1, p. 6). Sets are grown in field nurseries by seeding thickly (2–3 oz seed per square yard) in rows 5 inches apart or by growing under conditions that favor rapid bulbing. About 400–500 lb/acre of sets $\frac{1}{3}$ – $\frac{1}{2}$ inch in diameter is required. Generally, seed for the production of sets is sown in April through May to help ensure that the young seedlings will be exposed to the longest days possible during their two-to-three-leaf stage. About 6–8 weeks after sowing, the small bulbs are harvested, cured, and maintained in a shaded, well ventilated area. Holding sets larger than 1 inch in diameter at temperatures between 35° and 45°F will induce bolting. To plant sets

in the field, furrows 2 inches deep are prepared, and sets are dropped 3–4 inches apart in the row. Up to 25 acres of onions can be planted from sets grown in 1 acre of nursery. Onions grown from sets mature about 2 months earlier than when direct-seeded and about 2 weeks earlier than when grown from seedling transplants.

Irrigation

Onions require 1–2 inches of water per week, a total of 25–30 inches per crop for direct-seeded crops. More water is required during hot and windy conditions, and less water is required during cool, overcast weather. Because onion is a shallow-rooted crop, with most roots found in the top 12 inches of soil, it is sensitive to small changes in the water supply. Critical periods for irrigation are during stand establishment and the period of bulb development through maturity. Soluble salt levels in the irrigation water should not exceed 1200 ppm.

An evaporation pan can be used as a guide to irrigation amounts and frequency. Irrigation rates for onion should closely follow evaporation pan losses. This was recently confirmed for bulb onion production in CTAHR’s experiment station and on-farm research trials conducted by Dr. I-Pai Wu and Robin Shimabuku in Kula, Maui. At 3000 ft elevation, their work showed that evapotranspiration (ET) for a 133-day onion crop grown from December to April (after transplanting) was 17 inches, with a daily average ET of 0.127 inches (0.9 inch per week). A similar crop at about 1200 ft elevation had a total ET of 36 inches and a daily average ET of 0.2 inches (1.8 inches per week). Under warmer growing conditions at 3000 ft elevation, a 99-day onion crop grown from July to October resulted in an ET of 13.91 inches, with an average daily ET of 0.141 inches (1 inch per week). The irrigation studies also showed yield reductions equivalent to 1400 lb/acre for each inch of water below the optimal irrigation rate. In addition, yield reductions of 800 lb/acre were recorded for each inch of water applied in excess of the recommended irrigation rates. Overwatering also resulted in significant leaching of nitrate-nitrogen below the root zone.

Uniform soil moisture is required before and after sowing and during the early seedling growth stages. Adequate moisture also is necessary to ensure effectiveness of preemergence herbicides. Adequate moisture available to the crop results in good yields and minimizes stress. Onion seedlings are more tolerant of overwatering than of water deficit. Although raised beds

may improve drainage during rainy weather, a lack of moisture in the raised-bed system will result in yield losses. In California, for instance, an onion crop that received 18 inches of water in 6-inch raised beds resulted in bulbs half the size of those grown under flat culture.

Moisture stress during critical growing periods results in new growth when water availability resumes and, consequently, in a greater incidence of splits and doubles (Figure 2, p. 11). Under moisture stress, foliage growth slows and a gray to blue-green leaf color results from increased amounts of wax bloom on their surface. On the other hand, overirrigation results in yellowish-green leaves, reduced yield, and bulbs with a poor shelf life. Overirrigation, especially during cool weather, can also result in a greater incidence of pink root rot, which in turn predisposes the bulbs to fusarium bulb rots during the postharvest stages. Pythium root rot can also occur year-round when there is excessive moisture in the field. Excessive irrigation will also result in fertilizer leaching, particularly nitrogen. To minimize overwatering, maintain adequate soil moisture in the zone from 1 inch to 6–8 inches below the soil surface; water that percolates to soil levels deeper than 6–8 inches is lost to the onion crop. In CTAHR greenhouse trials with drip irrigation, yields increased with increasing irrigation levels up to 5 gallons per plant per growing season, but they decreased when more than 8 gallons per plant per season was applied.

The type of irrigation used will have an effect on insects, diseases, weeds, and other aspects of the production program. For example, overhead irrigation was shown to result in a greater incidence of sour skin of onion, caused by *Pseudomonas cepacia*, compared with furrow irrigation.

A dry bed surface is required during the ripening, harvest, and in-field curing stages. Therefore, irrigation is reduced as the bulbs start to mature and is stopped altogether about a month before harvest, as the bulbs begin to ripen (see Figure 3, the onion crop cycle, p. 14). The specific time to stop irrigation will vary depending on the current crop vigor, location, time of year, and cultivar used, but it generally occurs around the period when the tops start to fall. Excessive soil moisture during ripening can lead to regeneration of adventitious root growth from the stem, increased plant disease, and incidence of splits and doubles.

Wind protection

Onions are especially sensitive to strong wind during the initial 6–8 weeks of growth before reaching a height of 4–5 inches. Later in the season, as foliage grows, the onion plants provide some wind protection to each other. To provide adequate protection, windbreaks need to be established by the time onions are to be planted. Corn, sorghum, and rye are suitable as temporary windbreaks that can be disked over after the onion seedlings are 6 inches or higher. Sugarcane or wild cane are suitable as permanent windbreaks.

Integrated pest management for field onion production

What is integrated pest management?

The IPM approach

Integrated pest management (IPM) is a multifaceted, systems approach to reducing pest damage to crops based on the prediction of pest outbreaks and use of a holistic approach to maintain plant health. Its goal is to manage pest populations for optimum crop yield and quality and to maintain environmental quality. IPM is thus an overall strategy to use tactics that are practical, effective, safe for humans and the environment, and cost-effective. These tactics include growing plants that are genetically resistant to pests, releasing natural enemies of pest organisms, and modifying crop environments and cultural practices in ways that favor the crop while creating an unfavorable habitat for the pest. IPM promotes the use of nonchemical control practices to decrease reliance on and use of chemical pesticides.

The overuse and misuse of pesticides has led to negative consequences in terms of human health, environmental contamination, and the development of resistance in targeted pests. Since the days when the use of pesticides was considered a panacea to control major pests, approaches have changed. Now, farmers realize that there are better, environmentally compatible ways to manage pests, and consumers are also demanding more pesticide-free approaches.

IPM employs strategies and principles that have been part of agriculture throughout history. Before the development of synthetic pesticides, pests were managed in various ways, including

- applications of mineral oils, soaps, and plant extracts
- use of natural predators, barriers, traps, and trap crops
- modification of irrigation, crop rotation, and other cultural practices affecting crop environments
- utilizing strict sanitation and quarantine (isolation) practices.

The IPM approach advocates the continued use of such management strategies, along with scouting to forecast

pest populations and the prudent use of pesticides when necessary. “Prudent” implies that chemical pesticides are used only to avoid significant economic damage to the crop, and used in a manner that minimizes undesirable consequences to humans, beneficial organisms, and the crop environment.

Considerations for implementing an IPM program

Know the enemy and predict its occurrence

Become aware of potentially injurious organisms and determine their status as pests in your crop. Identify the key pests and establish an economic threshold for each one. A key to IPM programs is to predict pest occurrence and implement tactics to keep the pest population density below the level where cost of control exceeds the cost of damage. In today’s social environment, ecological and environmental considerations are as important as economic ones.

Monitor climatic conditions and pest populations. Pest populations are dynamic, as are weather conditions, crop growth, and populations of natural enemies. Devise a scouting schedule and design data sheets to record data. Include counts of onion thrips. Make random inspections of plants and roots for pests such as aphids, maggots, and caterpillars. Record the data for each pest and beneficial organism to determine whether a population is building or declining.

Growers can be alerted to the presence of pests even if they are not seen, because many pests produce damage symptoms or other evidence of their presence, such as cast skins and droppings. Know the activity patterns of pests and when to look for them. Some pests may be more active in the cooler times of the day, while others may be more easily spotted when it is warm.

For plant diseases, inspect plants weekly for any signs of rotted shoots or young leaves, yellowed or spotted leaves, or browning of roots. Monitor the tempera-

ture, humidity, and leaf wetness, and be alert for the conditions that favor specific plant disease pathogens. For example, *Botrytis* is favored by cool, damp conditions with at least six hours of leaf wetness. Bacterial diseases such as *Erwinia* and *Pseudomonas* are more prevalent during warm weather with high relative humidity. When the “warning” conditions exist, increase monitoring frequency, be on the look-out for early symptoms of the specific disease, and, if possible, adjust cultural practices to reduce the disease potential. Early identification of disease problems will allow you to prevent pathogen movement through the field. Make notes of suspicious symptoms and increase monitoring of the plants in the area. Use the monitoring data, the action thresholds set, and your experience to decide if a control measure should be taken.

Devise schemes for reducing populations of key pests to below economic threshold levels. Various management approaches, used singly or in combination, can produce this reduction. These approaches include cultural, biological, and chemical control practices, as described in the following sections.

Cultural control practices

Agricultural practices can modify the field environment to make conditions less favorable for a pest organism. These practices are often preventive measures, put into effect before the pest or pathogen is present. Some examples include crop rotations, field sanitation, and soil solarization.

Cultural controls include interventions that destroy or impair the pest’s breeding, feeding, or shelter habitat, such as field sanitation and weed control. Choosing among alternative ways of doing things can have significant effects on pests; for example, modifying the irrigation set-up to keep the crop’s leaves dry can make the crop’s micro-environment less conducive to plant disease build-up. Or, when applying pesticides, some cultural practices can alter the environment to increase the effectiveness of the pesticide.

The purpose of cultural controls in an IPM program is to maintain an environment that is not conducive to disease build-up. Moisture favors epidemics by enhancing the growth, spread, and infectivity of many pathogens. Moisture must be controlled to reduce and prevent diseases caused by bacterial and fungal pathogens. A field layout that provides good airflow can thus reduce the incidence of diseases.

Biological control practices

“Beneficials” such as parasitic wasps, predators, and diseases can help to control pest organisms. These allies may occur naturally, or they may be introduced. The use of biocontrols that do not occur naturally requires precise timing of applications. At the present time there are few commercial biological control organisms available in Hawaii because of the strict quarantine regulations in place to protect our unique, isolated environment from introductions of harmful organisms.

New beneficials such as fungi, bacteria, and nematodes are being developed as commercial products to control whiteflies, thrips, and other insects. Because of Hawaii’s insular nature, new biocontrol products face rigorous testing before being permitted entry to the state; however, a number of formulations of *Bacillus thuringiensis* (Bt) are available in Hawaii.

The indiscriminate use of pesticides often results in the depletion of beneficial populations. Sometimes growers can promote the activity of beneficial populations on their farms by using pesticides that are pest-specific instead of broad-spectrum.

Chemical control practices

Chemical control is a component of IPM. When cultural and biological controls do not bring about the desired results, pesticides may be required. The choice of pesticide, application rate, method of application, and frequency of application must be carefully coordinated to minimize hazards to workers, the crop, non-target organisms, and the environment. Select pesticides that are the most effective while being the least toxic. To minimize the possibility of resistance developing in the target pest or pathogen, rotate pesticides from different chemical classes. Check with your CTAHR Cooperative Extension Service agent or agrichemical supply dealer for information about newly registered pesticides that have a minimal impact on beneficial organisms and the environment.

To maximize efficacy of treatment, apply pesticides during the life cycle stage when the target pest is most vulnerable. Conversely, applications are not recommended when the target pest may be relatively immune to treatment or cannot be reached due to its physical location.

The goal of an IPM program is to maintain pest populations below an economically damaging level to produce a product that your customer will accept.

This guide provides information that was current at the time of printing. Growers should contact the nearest CTAHR Cooperative Extension Service (CES) office to inquire about the most current pest management recommendations. Current information about pesticides registered for onion can be obtained from CES or the Hawaii Department of Agriculture, Pesticides Branch.

Insect pests

Randall T. Hamasaki

This section provides basic information on the identification, biology, and management of important insect pests of onions in Hawaii. Successful management of insect pests in onion crops requires sound decision-making based on a thorough understanding of

- onion crop production techniques
- insect biology and pest interactions
- current pest management recommendations
- the ability to recognize both the pest and the beneficial organisms that may help to control it
- the use of IPM techniques including monitoring, application of effective insecticides with proper application techniques, record-keeping, and sound crop production practices.

Monitoring insects in the onion crop

Monitoring includes detecting, identifying, and sampling pest populations, preferably on a weekly basis. You must know the insect “enemy”—proper identification of pest insects and mites is the most important part of an effective pest management program. You should also be able to recognize allies—beneficial insects and mites that are natural enemies of plant pests and can often provide significant control, such as the tiny wasps that parasitize agromyzid leafminers.

Sound pesticide application techniques. Onion pests such as thrips are difficult to reach with insecticide sprays. Thorough pesticide coverage for control of these pests is recommended. To obtain optimal spray coverage, the spray equipment should be maintained in good working order and calibrated to deliver a known amount to a given area. Choice of spray adjuvants is important for coverage and treatment effectiveness. A field evaluation of spray adjuvants conducted on cabbage in Hawaii showed that Silwet L-77® (Loveland Industries, Inc.) provided the best performance, while

Sylgard® (Wilbur-Ellis Company) also provided good coverage. Other adjuvants performing fairly well included Excel 90® (Monterey Chemical Company), Activator 90® (Loveland Industries, Inc.), and R-11® Spreader Activator (Wilbur-Ellis Company).

Record-keeping. Record-keeping is a necessary part of farm life. Maintain accurate records on field location, soil and plant tissue analysis results, planting dates, fertilizer and pesticide applications, pest occurrences and their patterns, yield data, and other relevant production notes. A record of pest damage over a number of years may reveal trends that help you to prepare for similar problems in the future.

Sound production practices. The various practices described in this manual provide the basis for a balanced, stable, and productive cropping system. For example, appropriately matching onion varieties with local conditions and the growing season can help ensure optimum onion growth. You should be aware of conditions such as temperature, rainfall, and soil organic matter content that may favor or deter the development of particular pests. Fertilizer and irrigation practices should be calculated so that plants are kept healthy and can quickly recover from pest damage. Both deficiency and excess in applying fertilizer or irrigation can promote the development of certain pests and should be avoided. Pest problems can often be minimized by managing the planting location and timing, and by crop rotation. You should know which crops and weeds are “alternate hosts” that can harbor onion pests. Onion transplants and seedlings should be carefully produced to provide the crop with a healthy start. Good field sanitation practices are often critical in minimizing pest problems.

Insecticide resistance. A major concern for growers and pest management specialists is that insecticides may become ineffective because the pests develop resistance. Insecticides can become ineffective when pest populations exposed to the same insecticide treatment over several generations evolve with time to become comprised largely or entirely of resistant individuals. To prevent the development of insecticide resistance, use alternative nonchemical pest management strategies, rotate insecticides that have different modes of action, and apply insecticides based on the “action threshold” rather than the calendar or some arbitrary time interval.

Insect pests of onion in Hawaii

Insect pests of onion in Hawaii include thrips, leafminers, caterpillars, maggots, and aphids. Onion thrips is the

major insect pest of commercially grown bulb onions in Hawaii. Insecticide applications targeting onion thrips will also affect populations of other insects not targeted. For example, secondary pests like agromyzid leafminers occasionally become major pests when their populations build to high levels, often as a result of natural enemies being eliminated by intensive insecticide use. Therefore, growers need to balance insecticide applications used for control of onion thrips with the conservation of natural enemies of leafminers, which are killed by broad-spectrum insecticides. The beet armyworm is an occasional crop pest that growers should be able to identify and manage if the need arises. Other minor pests of onion in Hawaii are the Asiatic onion leafminer, onion aphid, western flower thrips, and seedcorn maggot.

Onion thrips, the major insect pest of onion

Onion thrips *Thrips tabaci* (Lindeman), Thysanoptera

Significance. Onion thrips is the major insect pest threat to bulb onion production in Hawaii and is present throughout the year. Large populations of thrips often develop despite the presence of natural enemies, and significant damage often occurs if effective pesticides are not applied. Heavy onion thrips infestations can kill young seedlings, reduce bulb quality and yield, and increase the incidence of foliar and bulb diseases.

Damage. Onion thrips have piercing-sucking mouth parts that are used to pierce and feed on individual plant cells. Thrips prefer to feed on the young, tender, inner leaves. Their feeding causes the leaves to develop a characteristic longitudinal whitish or silvery streaking or blotching (Figure 4). Black fecal specks may also be seen when thrips are present. Severe infestation causes leaves to develop brown tips, or the entire leaf may dry prematurely. Leaves may also become twisted and bend over (lodge).

Biology. The onion thrips is believed to have originated in the Mediterranean region and has become distributed throughout most of the world. This pest was first found in Hawaii in 1915 and is now present on all the islands. Onion thrips life stages include the egg, first larva, second larva, prepupa, pupa, and adult (Figure 5). It is important to remember that only adults have fully developed wings, which enable them to fly, and also that pupation takes place in the soil, where the insects are less likely to be contacted by insecticides.

The time from egg to adult is about 19 days. Large thrips populations are able to develop quickly under

Hawaii's weather conditions, and many overlapping generations occur throughout the year. Reproduction of onion thrips in Hawaii is mostly through a process called parthenogenesis, in which females are able to reproduce without mating. As a result, onion thrips populations consist of 1000 females for every male.

Eggs. Female onion thrips have a saw-like structure called an ovipositor, which serves to make an incision in the plant tissue for egg-laying. The eggs are placed singly, just under the epidermis of succulent leaves, flowers, stems, or bulbs. The eggs are elliptical and very small (about $\frac{1}{125}$ inch, or 0.2 mm, long). They are whitish when deposited and later develop an orange tint. Hatching generally occurs in 4–5 days in Hawaii.

Larvae. The egg hatches into the first-instar larva, which is whitish to yellowish. The first-instar larva molts into the second-instar larva, which is larger. Both of the larval stages feed on plant tissue. Larval development is completed in about 9 days.

Pupal stages. There are two nonfeeding stages, the prepupa and pupa. Mature second-instar larvae burrow into the soil to molt into these nonfeeding, resting stages. The combined prepupal and pupal developmental period is generally completed in 4–7 days. The two nonfeeding stages that occur below the soil surface make it difficult to control this pest, because the individuals are protected from foliar insecticide applications.

Adults. The adult thrips emerges from the pupa and is about $\frac{1}{25}$ inch (1 mm) long (Figure 5). Its body color ranges from pale yellow to dark brown. Its tiny wings are unbanded and dirty gray. In Hawaii, this species has a darker form during the cool season. Males are wingless and extremely rare. Females live for about 2–3 weeks, and each can lay about 80 eggs.

Hosts. Onion thrips prefer to feed on onions and other alliums, but they also feed on many cultivated crops as well as uncultivated plants in at least 25 families. Among the crop hosts are bean, broccoli, cabbage, carnation, carrot, cauliflower, celery, Chinese broccoli, cotton, cucumber, garlic, head cabbage, leek, melon, orchids, papaya, peas, pineapple, rose, squash, and tomato.

Biological control. Several parasitic wasp species were introduced to Hawaii in the 1930s in an attempt to help control the onion thrips. Only one, however (*Ceranisus menes*), became established, and its impact on onion thrips is not considered to be significant. Onion thrips are also subject to a variety of general predators such as spiders, minute pirate bugs, predaceous thrips, and predaceous mites, which occur throughout most onion fields. Unfortunately, these natural enemies do not gen-



Figure 4. Onion thrips damage to onion.



Figure 5. An adult onion thrips (about 40 times life size).



Figure 6. Inspecting the leaf axils for onion thrips. The action threshold is when more than 100 thrips are counted on 10 or fewer plants.



Figure 7. Leafminer damage to onion.



Figure 8. Beneficial wasp parasitizing a leafminer maggot.



Figure 9. Beet armyworm and damage.



Figure 10. Asiatic onion leafminer damage.



Figure 11. Asiatic onion leafminer pupa.

erally provide economically effective control of this pest. Onion thrips populations therefore need to be closely monitored and controlled with insecticides when the action threshold is reached.

Other natural control factors. Rainfall and temperature are probably the most important natural factors controlling thrips populations. Thrips populations are often greater during the warmest months of the year in Hawaii (July–September). Sprinkler irrigation is sometimes used to control thrips.

Monitoring and action threshold. Scouting for thrips consists of inspecting individual plants in the field and counting the number of thrips present. The “action threshold,” the level at which it has been determined that management action should be taken, is based on the average number of thrips per plant observed during monitoring. Monitoring and treatment is necessary only during the pre-bulbing stage of crop development (see Figure 3, p. 14). Based on a field trial conducted at the Kula Research Station in 1998, an action threshold of 10 thrips per plant was suggested. A grower should consider counting 10 plants per site. If monitoring finds a total of 100 thrips after less than 10 plants are inspected, the decision would be to spray. For example, if monitoring finds a total of 100 thrips after only four plants are counted, the decision would be to spray. If monitoring finds a total of 90 thrips after 10 plants are inspected, the decision would be not to spray, because the action threshold of an average of 10 thrips per plant was not exceeded. Use of a hand lens is recommended for monitoring thrips. Careful attention should be given to the leaf axils, where thrips often hide (Figure 6, p. 23).

Cultural control. Prompt destruction of cull piles and turning under of crop debris by cultivation after



Figure 12. Onion aphids.

Table 5. Evaluation of insecticides for control of onion thrips in dry onions; average number of thrips found per plant six days after treatment, Kula, Maui, 1996.

Treatment	Rate (a.i.)	Number of thrips ^z
Warrior II 1 EC	0.02 lb	7.03 d
Malathion 5 EC	2.5 pt	22.30 c
Lannate LV	3.0 pt	46.90 ab
Diazinon AG500	1.0 pt	51.38 ab
Untreated control	0	57.08 a

^zAverages in each column followed by a different letter are significantly different (Tukey's studentized range test, $P < 0.001$, SAS for Windows ver. 6.11); data were transformed by square root ($X + 0.5$) before analysis; untransformed means are given.

harvest reduces the abundance of onion thrips. Other necessary sanitation techniques include weed control and separation of crops in space or time. Measures should be taken so that transplants are as free of onion thrips as possible. Knowledge about alternate host plants is important to onion thrips management. For example, onion thrips populations could build up to high levels in cabbage plantings and move onto nearby onion plantings when the cabbage is harvested.

Chemical control. The timing of insecticide applications should be based on need as determined by monitored thrips population counts. Specific control recommendations for onion thrips vary among regions and are based on experience, research, and the increasing threat of insecticide resistance. Unnecessary insecticide applications increase production cost, the risk of insecticide resistance, environmental hazard, and outbreaks of secondary pests such as leafminers. Certain thrips populations are resistant to some pesticides, a trend that varies with the history of insecticide use against them. There-

fore, differences in insecticide effectiveness may exist between individual farms. For example, methomyl (Lannate®) is frequently used in many onion producing areas for onion thrips control. However, methomyl is not effective for onion thrips control on Maui because of resistance resulting from intensive use of this insecticide (see Table 5). Similarly, in New York state, onion thrips showed tolerance of Ambush®, Mustang®, and Warrior® applications in commercial onion fields, with variations in tolerance observed from area to area and from farm to farm within an area. The variation in insecticide tolerance observed in the New York survey was likely affected by the spraying practices of the individual farmers.

Insecticides. Synthetic pyrethroid insecticides such as Warrior® (lambdacyhalothrin) and Ammo® (cypermethrin) are very effective in controlling onion thrips. Other insecticides commonly used for onion thrips include malathion, diazinon, oxamyl (Vydate®), and azinphos-methyl (Guthion®). The effectiveness against thrips of some commonly used insecticides was evaluated in Kula, Maui (Table 5).

Onion thrips resistance management. Utilizing appropriate cultural pest management strategies and applying insecticides based on the action-threshold method are the basic approaches to resistance management. An additional strategy is to rotate different classes of insecticides. Malathion could be used to suppress thrips populations in rotation with Warrior® or Ammo®. Diazinon was not effective in the 1996 trial in Kula but may be effective in other localities depending upon the history of insecticide use.

Secondary and occasional pests

Agromyzid leafminers	(Diptera, Agromyzidae)
Pea leafminer	<i>Liriomyza huidobrensis</i> (Blanchard)
Vegetable leafminer	<i>L. sativae</i> Blanchard
Celery leafminer	<i>L. trifolii</i> (Burgess)

Significance. Agromyzid leafminers are secondary pests that can become a primary and serious problem when their numbers build to high levels. Leafminer population explosions often occur as a result of broad-spectrum insecticide applications, which destroy their natural enemies. Leafminer adults are small flies, and their larvae are tiny maggots with chewing-type mouth parts. Losses due to leafminers are caused mainly by their larvae, which feed by tunneling through the leaf.

The larvae live in the layer of plant cells just beneath the leaf epidermis and create winding trails (“mines”) as they feed. In green onions, leaves can be completely girdled by larval feeding, causing the onion leaves to die when leafminer numbers are high (Figure 7, p. 23). Adult leafminers also cause stippling (tiny whitish spots) on the leaves by their feeding and egg-laying activities.

Three species of leafminers have been recorded infesting bulb onion in Hawaii. The pea leafminer is the most important leafminer species in commercial bulb onion plantings in the Kula and Pulehu areas of Maui, whereas the vegetable leafminer is the predominant species infesting green onion plantings in Waianae, Oahu. In addition to causing direct damage, leafminers also contribute to indirect damage by allowing the entry and development of certain onion diseases.

Biology of the pea leafminer

Eggs. Females lay an average of 8–14 eggs per day. Eggs are laid singly but often in close proximity under the epidermal cell layer. The whitish, translucent egg is about $\frac{1}{100} \times \frac{4}{1000}$ inch (0.25 x 0.1 mm). The egg stage lasts from $1\frac{1}{2}$ to 4 days, depending on temperature and on the host plant.

Larvae. The larvae (maggots) hatch from the eggs and feed in the spongy mesophyll of the leaf. There are three larval stages, which become progressively larger with each molt. The larval stage may last from 4 to 10 days depending on the temperature and host plant.

Pupal stages. The maggot chews a hole in the leaf surface and emerges from the leaf to pupate. There is a fourth larval stage before actual pupation, the prepupal stage, which lasts only 4–5 hours. The pupae vary in size from $\frac{6}{100}$ to $\frac{13}{100}$ inch (1.6 to 3.25 mm) long by $\frac{3}{100}$ to $\frac{4}{100}$ inch (0.7 to 1.1 mm) wide. The pupa varies in color from light brown to almost black. Pupation may occur on the ground or on the plant. The pupal stage lasts 8–13 days.

Adults. Adults are about $\frac{8}{100}$ inch (2.1 mm) long. Females live up to 18 days and males live about 6 days. Female adults puncture the upper leaf surfaces with their ovipositor and feed at these holes. These feeding punctures produce a stippled appearance on the leaf. The males, which lack an ovipositor, also feed in these punctures. Eggs are laid in only a small portion (5–10%) of these feeding punctures.

Hosts. The pea leafminer feeds on a wide range of flowers, vegetables, and weeds. Some of its host plants

include bean, beet, Chinese cabbage, celery, cucumber, daikon, eggplant, lettuce, melon, parsley, pea, pepper, potato, radish, spinach, and tomato.

Biology of the vegetable and celery leafminers

The life cycle of these leafminer species is similar. The average period of the life cycle from egg to adult is 21 days, but it can be as short as 15 days. The length of the life cycle varies with the host plant and temperature.

Egg. Female adult flies lay eggs singly in punctures in the leaf epidermis. There is no egg-laying preference between the upper or lower surface. The freshly laid eggs are creamy white and shaped like an elongated oval. The eggs are $\frac{1}{100}$ inch long and hatch in 2–4 days.

Larva. The maggot is bright yellow to yellow-green and measures about $\frac{1}{8} \times \frac{1}{50}$ inch (4 x 0.5 mm). Each of its three larval stages is completed in 2–3 days.

Pupal stage. The pupal stage is yellow-brown and distinctly segmented. Pupae are rectangular with oval narrowing at the ends. This stage does no feeding damage, and development is completed in 5–12 days.

Adult. The adult is a tiny fly about $\frac{1}{12}$ inch (2 mm) long, matt-gray with black and yellow splotches. It lives for 10–20 days, depending on environmental conditions.

Hosts. There are over 20 hosts in the Cucurbitaceae, Fabaceae, Solanaceae, and Brassicaceae plant families. In Hawaii, vegetable and celery leafminers are considered pests of bean, broccoli, cauliflower, celery, Chinese cabbage, wintermelon, cucumber, eggplant, hyotan, lettuce, luffa, pepper, pumpkin, squash, tomato, watermelon, yard-long bean, and zucchini.

IPM for leafminers in onion

The major approach to managing leafminers in onion is to conserve their natural enemies by minimizing applications of broad-spectrum insecticides. The application of insecticides to control onion thrips and other targeted insect pests should be based on need as determined by monitoring rather than on a calendar-based schedule.

Biological control. Over 10 species of tiny wasps commonly parasitize leafminers in Hawaii (Figure 8, p. 23). The type of crop often influences which parasite species are present. On Maui, *Halticoptera circulus* comprised up to 95 percent of the leafminer parasites recovered from onion crops, while *Chrysocharis* sp. comprised 5 percent. Similarly, the leafminer parasites *H. circulus* and *Ganapidium utilis* appeared to suppress leafminer populations in celery in Kamuela, Hawaii, in the ab-

sence of pesticide treatments. The use of broad-spectrum insecticides can cause leafminer population outbreaks due to the destruction of these wasp-like parasites. In the absence of their natural enemies, leafminer populations build to higher levels. As a result, greater crop loss from increased infestation levels occur. Thus, pesticide applications targeting onion thrips must be balanced with the conservation of natural enemies that control leafminer populations.

Cultural control. Studies on the use of cultural control methods have been few, and the results are not very promising. Row covers are effective in excluding leafminers but are more expensive than chemical controls. Field studies in Hawaii intercropping bush beans with onion neither reduced leafminer populations nor increased activity of leafminer parasitoids.

Insecticidal control. Chemical control of leafminers is difficult because of their short life cycle, the small size and high mobility of the adult flies, the relatively long pupal stage occurring in the soil, their high reproductive potential, and the protection of eggs and larvae in plant tissue. Another important factor contributing to the difficulty of controlling leafminers with insecticides is the development of insecticide resistance. For example, green onion growers in Waianae reported that registered insecticides did not effectively suppress *L. sativae*. Elsewhere in Hawaii, intensively treated *L. sativae* populations became 13 times more resistant to pyrethroids than populations not heavily sprayed. Commonly used insecticides can quickly lose their effectiveness as resistant populations are selected with frequent use. Therefore, onion growers should not rely on insecticides as a long-term management strategy for leafminers. Rather, effective insecticides should be applied only when needed and as determined by monitoring. Work is in progress to register effective insecticides for leafminer control in Hawaii-grown onions.

Beet armyworm

Spodoptera exigua (Hubner); Lepidoptera, Noctuidae

Significance. Beet armyworm caterpillars occasionally cause significant onion crop damage. On green onions in Waianae, it is a significant pest primarily during the winter months, when its voracious feeding causes plant defoliation. Other crops attacked include basil, broccoli, beet, bean, cabbage, carrot, Chinese broccoli, corn, lettuce, pea, pepper, potato, soybean, spinach, sweetpotato, tomato, rose, and chrysanthemum. First found in Hawaii in 1880, the beet armyworm is now present on

Hawaii, Kauai, Maui, and Oahu.

Egg. On onions, the eggs are deposited in clusters of 20–100, covered by a white, hair-like material that makes the clusters resemble small cottonballs. The eggs are visible if the protective material is lifted. The egg is a flattened half-sphere, white to pinkish, with fine lines radiating from the top center. Eggs hatch in 5–7 days in warm weather.

Larva. The larva (caterpillar) molts five times within a minimum of 16 days. The caterpillar grows progressively larger with each molt, with the last larval instar attaining a length of 1½–2 inches. The color of the larger larva ranges from bright green to purplish green to blackish (Figure 9, p. 23). The most common color phase is light green with a dark stripe down the back and a paler stripe along each side. Latter stages of beet armyworm larva are much larger than larva of the leek moth. The latter-stage larvae are often protected within the hollow onion leaves and are more difficult to control.

Pupa. Pupation occurs on or under the soil surface. The pupa is brownish and about ¾ inch long. The pupal stage lasts about 17 days.

Adult. The adult moth is smaller than most other armyworm or cutworm moths, approximately ½ inch long with a wing spread of 1–1½ inches. The body and wings range from silver-gray to grayish brown. The forewings have a lighter spot near the center, while the paler hindwings have dark borders with a light band at the wing edges.

Management. The control of broadleaf weeds and the rapid disposal of crop residues after harvest may help to reduce pest levels. Little is known about the importance of natural enemies in controlling the beet armyworm in Hawaii. Populations of beet armyworm have been easily controlled with insecticides in Hawaii, in contrast to U.S. mainland experience. Synthetic pyrethroids and methomyl can be used for beet armyworm control if needed (see Appendix A). *Bacillus thuringiensis* (Bt) insecticides are effective in controlling certain caterpillar pests only when the bacteria are ingested. Control of beet armyworm in onion using Bt is limited because the larvae live and feed within the hollow onion leaves. In general, spray applications targeting the early larval stages and good spray coverage provide the most effective control. Bt insecticides are specific to caterpillar pests and pose little harm to beneficial insects and mites.

Minor insect pests of onion

Asiatic onion leafminer

Acrolepiopsis sapporensis (Matsumura); Lepidoptera, Acrolepiidae

The Asiatic onion leafminer (also known as the allium leafminer) is a minor pest of onion in Hawaii. Growers should not confuse the Asiatic onion leafminer with agromyzid leafminers. Asiatic onion leafminer larvae are small caterpillars that damage plants by chewing on and living within the tubular onion leaves (Figure 10, p. 23). The Asiatic onion leafminer was first recorded in Hawaii in 1939 on the island of Oahu, although it was then mis-identified as the European onion leafminer (leek moth), *Acrolepia assectella*. The Asiatic onion leafminer is also found on the islands of Hawaii, Maui, and Kauai. The caterpillars are about ⅓–⅜ inch long when mature and are much smaller than beet armyworm caterpillars.

After slight mining, the small caterpillars usually penetrate the onion leaf near the tip and feed inside the hollow leaf. Holes are sometimes eaten to the exterior again, but more commonly the damaged internal areas appear on the outer surface of the leaf as pale spots. Extensive feeding may cause the tips to dry. Caterpillars boring into the bulb near the leaf base may allow entry of bulb-rotting organisms. There are five larval stages (instars). The pupae (cocoons) are usually visibly attached to the outside of the leaves (Figure 11, p. 24). They also pupate on the soil or near plants. At 77°F, the average egg incubation period is 3 days, the larval period is 13 days, and the pupal period is 7 days.

Adult moths have a wing span of approximately ⅓ inch. The forewings are ash colored, approaching black. The forewing has a large, white, triangular marking with smaller markings. The hindwings are gray, approaching black. Adults roughly resemble the diamondback moth in size and general appearance. Little is known about the natural enemies of the Asiatic onion leafminer in Hawaii. Insecticides generally effective for the beet armyworm should provide control should the need arise (see Appendix A).

Seedcorn maggot

Delia platura (Meigen); Diptera, Anthomyiidae

The seedcorn maggot is a minor pest of onion in Hawaii. Failure of seed germination or seedling emergence is usually the first sign of infestation. The seedcorn maggot can be a serious pest of bean and corn. Other crops

attacked include cabbage, cucumber, lettuce, pea, and potato. Crop damage occurs when the maggots burrow into seeds or seedlings. The maggots begin feeding on germinating seeds or organic matter soon after hatching. Partially decayed seeds or injured seeds are its favorite food sources.

Biology. Eggs are deposited close to seeds in soil where there is abundant organic matter, seeds, or seedlings. Adult females lay an average of 100 eggs over a 3–4 week period. Maggots are yellowish white to dirty yellow, legless, and measure approximately ½ inch in length and ¼ inch in girth in their later stages. The three larval stages are completed in 12–16 days. The mature larvae pupate in the first 2–3 inches of soil a short distance away from the host plant. Pupae are tan to brown and less than ¼ inch long. The pupal stage lasts 7–20 days. Adult flies are brown, about ½ inch long, and are often mistaken for small houseflies. Adults may live for 4–10 weeks. Development of seedcorn maggots from egg to adult takes 21–40 days.

Management. The greatest damage occurs in cool, wet seasons and in soils containing large amounts of organic matter. A preventive measure against seedcorn maggot infestation is to plant when the soil and weather promotes rapid germination. If using manure, let it age and incorporate it thoroughly into the soil. Preventive seed treatment with either a soil-applied granular insecticide or an insecticide seed-coating has been effective.

Onion aphid

Neotoxoptera formosana (Takahashi); Homoptera, Aphididae

Commercial bulb onion plantings are rarely bothered by the onion aphid in Hawaii. This aphid (Figure 12, p. 24) was described in Taiwan and was first recorded in Hawaii from specimens collected in Kaneohe, Oahu, in 1939. Host plants include green onion, chive, garlic or Chinese chive, bulb onion, and pole bean. Wingless adult onion aphids are about $\frac{9}{100}$ to $\frac{1}{100}$ inch (1.6 to 2.3 mm) long, oval, and shiny magenta-red to almost black. Winged forms are very dark red to black. Their wings are netted with conspicuous dark veins. Onion aphid populations are generally kept under control by natural enemies, although outbreaks may occur on garlic chive or green onion in home gardens.

Western flower thrips

Frankliniella occidentalis (Pergande); Thysanoptera, Thripidae

Although the western flower thrips is distributed throughout all the major Hawaiian islands except Molokai, it is not a significant pest of onion in Hawaii. However, the western flower thrips has caused significant onion crop damage in onion-producing areas of the southern USA, such as Texas. Growers may have difficulty in differentiating between onion thrips and western flower thrips. Thrips and other insects have structures called “simple eyes” (ocelli), which are used for visual sensing. The simple eyes will appear as three small circular structures located between the large compound eyes. The simple eyes of the western flower thrips have a red pigment, whereas those of the onion thrips are gray. Growers can have thrips identified for a nominal fee by submitting samples of onion plants infested by thrips to the CTAHR Agricultural Diagnostic Service Center via CTAHR Cooperative Extension Service offices.

Onion diseases

Robin S. Shimabuku

Pink root

Pink root is one of the most serious diseases of onion in Hawaii. This disease, caused by the fungus *Phoma terrestris* H.N. Hans. (synonym *Pyrenochaeta terrestris* [H.N. Hans.] Gorenz, J.C. Walker, and R.H. Larson), occurs in many commercial onion producing areas throughout the world and is most devastating in warm-tropical and subtropical climates.

Symptoms. Infected roots are light pink at first, and as the disease progresses the color darkens to deep pink, to red, and finally to dark purple in the advanced stages (Figure 13). In acid soils, the infected roots may appear yellow. In the early stages of the disease, the roots lose their turgidity and are semitransparent and water-soaked. In the advanced stages, the roots shrivel and die. As new roots develop, they also become infected and die. Although the disease seldom kills the plant, severely infected plants are stunted, show symptoms of nutritional deficiencies, have fewer and smaller leaves, and tend to bulb earlier. Infected seedlings may die or produce unmarketable bulbs that are small or shriveled.



Figure 13. Pink root symptoms.



Figure 14. Gray to brownish rot on onion basal plate caused by *Fusarium oxysporum* f. sp. *cepae*.



Figure 15. Early leaf symptoms of downy mildew on onion.

(Reprinted by permission of the American Phytopathological Society, ©1995.)



Figure 16. Advanced stage of downy mildew leaf symptoms on onion.

(Reprinted by permission of the American Phytopathological Society, ©1995.)



Figure 17. Purple blotch leaf symptoms caused by *Alternaria porri*.

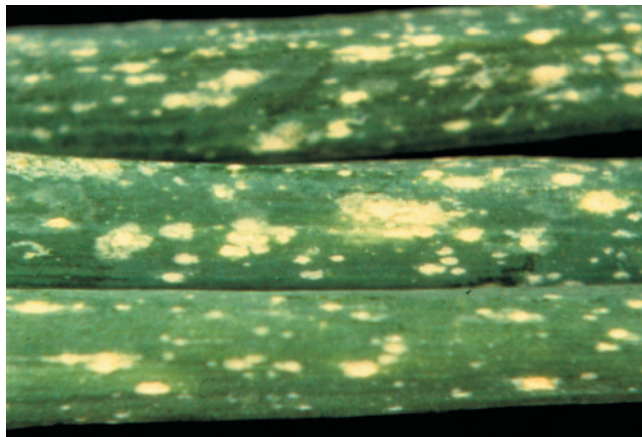


Figure 18. Botrytis leaf blight lesions on onion leaves.
(Reprinted by permission of the American Phytopathological Society, ©1995.)



Figure 19. Black mold, *Aspergillus niger*.



Figure 20. Onion field damaged by bacterial soft rots.



Figure 21. Cross-section of an onion bulb infected with bacteria.



Figure 22. Bacterial soft rot, *Erwinia carotovora*.

Disease cycle and biology. The fungus lives within the top 1½ feet of the soil surface and survives as small fruiting bodies (microsclerotia) in plant debris. The disease occurs only on onion roots and not on the basal plate or fleshy portions of the bulb. Infection by pink root can predispose the plant to fusarium basal plate rot disease. Optimal soil temperature for the pink root fungus development ranges from 75° to 85°F. At 68°F there is reduced infection of roots, and below 61°F very little pink root infection occurs.

Disease management strategies

Cultural practices

Crop rotation. To reduce disease pressure, onions should be planted in a 3- to 6-year rotation with plants that are not susceptible hosts of the fungus. Susceptible host plants that should not be grown in rotation with onion include corn, soybean, tomato, eggplant, pepper, squash, cucumber, cauliflower, cantaloupe, spinach, carrot, English pea, oats, barley, and ryegrass. Pink root becomes most severe when onions are grown in continuous monoculture.

Resistant varieties. Commercial onion cultivars have a wide range of resistance to pink root disease, and where pink root is a problem, the goal is to find a resistant cultivar with appropriate horticultural characteristics. Tolerance of pink root disease may be related to a plant's ability to regenerate new roots in the presence of infection, rather than any inherent resistance of the roots to infection by the fungus. Disease "resistance" may be limited by high temperatures (above 83°F).

Soil solarization. In studies conducted in the USA and Israel, soil solarization reduced the incidence and severity of pink root and increased onion yields. This method involves raising the soil temperature by covering it with clear polyethylene plastic for a month or longer, and it is most effective when done during hot, sunny seasons, such as mid-summer in Hawaii. The soil should first be tilled and moistened before covering it with the plastic sheet.

Reducing plant stress. Good management practices that allow the onion plant to grow vigorously and take up adequate amounts of nutrients and moisture can reduce crop losses due to pink root. These practices include maintaining good soil tilth and fertility, managing moisture well, and controlling other insect pests and diseases that reduce the onion plant's ability to regenerate new roots.

Chemical control

Soil fumigation before planting has been shown to be very effective in increasing yields in fields infested with pink root. Currently, the most commonly used soil fumigants are metam-sodium (Vapam®) and chloropicrin (Telone C-17®). In Australia and Texas, studies showed that the use of soil fumigants in conjunction with soil solarization is more effective than using either individually.

Fusarium basal plate rot

Fusarium basal plate rot is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cepae*. The disease occurs worldwide and causes significant onion losses in many countries. In Hawaii, this disease has caused annual yield losses of 10–40 percent, according to Maui growers.

Symptoms. Initial symptoms of the disease are progressive yellowing and dieback of the onion leaf tips. Decay of the stem plate is normally associated with these early foliar symptoms. As the disease progresses, dieback occurs from the older to the younger leaves. Diseased roots eventually rot, and the infected basal plate has a gray to brown discoloration (Figure 14, p. 29). Infected bulbs are discolored, and when cut open the diseased tissue appears brown and watery. During rainy and humid weather, a whitish growth of fungal mycelia can occur on the diseased basal plate and scales. Plants infected late in the growing season may appear normal at harvest, but the rot will continue from the stem plate into the bulb and become a postharvest problem.

Disease cycle and biology. The fungus *Fusarium oxysporum* f. sp. *cepae* persists in the soil for many years and survives in infested crop residues or by producing chlamydospores (overwintering spores). Optimum temperatures for disease development are 77–82°F, and the disease is not prevalent at temperatures below 59°F.

The fungus can directly infect normal, healthy roots, although disease incidence is greatly increased if the roots, stem plate, or bulb has been wounded. Wounding can be caused by cultivation, transplanting, thinning, pink root infection, insects (onion maggot, wireworm), herbicide damage, etc. The disease is more prevalent in transplanted onions than in direct-seeded onions. In storage, disease spread from bulb to bulb is not a major problem. The fungus is primarily spread from field to field by water, insects, and the movement of infested soil with farm tools and equipment.

Disease management strategies

Cultural practices

Crop rotation. A 3- to 4-year rotation with a crop that is not an *Allium* species (onions, garlic, leeks, chives, etc.) is recommended to reduce the incidence and severity of the disease. Some suitable nonhosts of *Fusarium oxysporum* are beet, carrots, lettuce, and spinach. However, with both *Fusarium* and *Phoma* present in Hawaii, carrots and spinach should not be used as rotation crops.

Resistant varieties. The use of resistant varieties has been the most important control measure. At present, however, no sweet onion cultivar with resistance to basal plate rot is available, and only pungent Spanish types are known to have resistance. Growers should check with seed company representatives for information on availability of new resistant cultivars.

Postharvest handling. At harvest, cure onions properly before storage. Ensure that packing sheds and storage areas are dry and well ventilated. Carefully sort and remove diseased bulbs before storage. Losses during storage or in transit can be minimized by storing bulbs at 39°F, because warm conditions favor disease development.

Mechanical injury to bulbs must be avoided during cultivation, spray applications, and harvest to minimize pathogen entry through wounds.

Chemical control

At present, there is no chemical control available. However, in Japan, the use of fungicidal dips to transplanted seedlings has significantly reduced disease losses.

Downy mildew

Downy mildew is a serious disease affecting onion leaves. It is caused by the fungus *Peronospora destructor* (Berk.) Casp. and is widely distributed throughout the Americas, Europe, China, Japan, New Zealand, Africa, and the Middle East. This disease is most prevalent during cool, moist weather conditions, which can occur at higher elevations in Hawaii, and it is not as much of a problem in warm conditions.

Symptoms. The disease appears during periods of high humidity as elongated lesions on the surface of older leaves (Figure 15, p. 29). The lesions appear bluish-purple, and a fine, furry, grayish-white growth may be seen on the surface of the leaf during periods of high moisture. Affected leaf tissues are pale green, later turn

yellow, and eventually collapse, killing the entire leaf (Figure 16, p. 29). The fungus is only able to produce spores on young leaves. To detect the early presence of the disease in the field, look for small, circular, yellow patches of diseased plants that tend to enlarge in the direction of the prevailing winds. Under warm, dry weather conditions with temperatures exceeding 75°F and relative humidity below 80%, the disease will nearly disappear, but it may reappear during cool, moist conditions.

Disease cycle and biology. Downy mildew overwinters on crop debris such as cull piles and diseased bulbs left in the field. The fungus produces spores at night when humidity is high and temperatures are between 39° and 77°F. Ideal temperature for sporulation is 55°F. The spores are dispersed by the wind the following day and remain viable for 3–4 days. Infection requires temperatures below 72°F and leaf surface moisture from rain, dew, or relative humidity greater than 95%. The disease cycle is completed in 15–23 days, which includes a few days for sporulation, dispersal, and establishment of new infections.

Disease management strategies

Cultural practices

Sanitation. Good sanitation practices reduce the incidence of downy mildew in the field by minimizing the amount of fungal inoculum present. These practices include removal and destruction of culls, crop debris, and volunteer onion plants.

Crop rotation. Because this fungus attacks only onion relatives, a 2- to 3-year rotation with nonhost crops can reduce levels of inoculum in the field. Avoid planting *Allium* species such as garlic, chives, and shallots in the vicinity of onion plantings.

Creating conditions unfavorable for the disease organism. Avoid dense plantings and windbreaks that create the humid conditions that favor disease development. The use of overhead irrigation is discouraged, but when it is necessary, irrigating in the morning rather than in the afternoon will help reduce moisture levels on the leaves at night. Avoid excessive nitrogen fertilizer applications. Orient onion rows in the direction of prevailing winds to lower field humidity. Avoid poorly drained soils, or, if drainage is poor, plant on raised beds.

Seedling production. Because spores of *Peronospora* are spread by air movement, great care must be taken to protect onion seedlings from this disease. They should not be grown near fields where the disease is present. Under humid conditions, the use of commer-

cial potting media, raised benches, and a solid cover (clear plastic or fiberglass roof) can help reduce seedling susceptibility to downy mildew.

Chemical control

Fungicides should be applied at the first sign of the disease or when conditions become favorable for disease development. It is very important to cover the leaves with the spray. Fungicides currently labeled for use in onion in Hawaii are listed in Appendix A.

Purple blotch

Purple blotch is a serious disease caused by the fungus *Alternaria porri* (Ellis) cif., which attacks the foliage of bulb and green onions and leeks. Outbreaks of purple blotch are common throughout the world, but the disease is most serious in areas that experience hot and humid weather. Onion yield losses from purple blotch have exceeded 50 percent in some production areas.

Symptoms. The disease first appears as small water-soaked flecks (<1/8 inch diameter) that enlarge into zonate, brown to purple spots or lesions 1–2 inches long (Figure 17, p. 30). The margins of the spots are reddish-purple and fringed by a yellow zone. In moist conditions, the surface of the lesion is covered with the dark, powdery, brown to black spores of the fungus. Within several weeks after lesions appear, severely affected leaves develop blights and die. Heavily diseased plants may lose all leaves and die. Bulbs are occasionally attacked as they near harvest, and normally a few of the outer scales are affected. Bulb rots start as watery decays on the neck region and appear as a deep yellow to wine-red discoloration. As these tissues dry, the affected scales develop a papery texture.

Disease cycle and biology. The purple blotch fungus survives from one season to the next primarily on infested crop debris and other *Allium* species. As conditions become favorable for the disease, the fungus will produce spores that are disseminated by wind, rain, or overhead irrigation. In some cases, the fungus is seed-borne. Conditions that favor purple blotch development are temperature over 77°F and relative humidity over 90%. Disease pressure, therefore, is highest during periods of warm weather and extended wet conditions due to rain or heavy dew. Under favorable conditions, the purple blotch fungus can form spores overnight and thus can spread very quickly. Leaf wetness for periods of 9–11 hours are conducive for spore production and infection. Older leaves generally are more susceptible to in-

fection than younger ones, but young leaves infested with thrips are susceptible. Young leaves also tend to become more susceptible as the bulb nears maturity.

Disease management strategies

Cultural practices

Crop rotation. Rotation for 2–3 years with plants that are not *Allium* species will reduce incidence of purple blotch.

Sanitation. Remove all infected plant material from the field.

Creating conditions unfavorable for the disease organism. All practices that reduce leaf wetness (decreased planting density, good soil drainage, drip irrigation, scheduling irrigation early in the day) can reduce the amount of infection in the field.

Chemical control

Fungicides can reduce the incidence and severity of the disease. Because onion leaves are increasingly susceptible as they mature and near bulb maturity, a single spray application is not recommended. The concept of “leaf wetness hours” (LWH) suggested by Schwartz (1995) can be used as a guide for a fungicide spray program. By tracking the amount of LWH per day, the fungicide spray interval can be adjusted, based on the potential for disease development. If the LWH exceeds 12 hours per day, the spray interval should be shortened. Conversely, if the LWH is less than 12 hours per day, the spray interval may be extended by several days. It is very important to provide good spray coverage on the leaves for good control. Fungicides currently labeled for use in onion in Hawaii are listed in Appendix A.

Botrytis leaf blight, botrytis neck rot

In Hawaii, botrytis leaf blight and neck rot are significant diseases of onion caused by *Botrytis squamosa*, *B. cinerea*, *B. allii*, and other *Botrytis* species.

Symptoms. The initial leaf blight symptoms appear as small, white, sunken, necrotic (dead tissue) spots about 1/20–1/4 inch in diameter (Figure 18, p. 30). Sometimes the necrotic spot is surrounded by a light green halo. As the disease progresses, the leaf spots may expand and become oval in shape. A rapid dieback from the leaf tips (a blighting effect) occurs as leaf spots on the leaves become more numerous. Under prolonged wet, cool, and humid conditions, the disease can spread rapidly

throughout the field. If this disease is allowed to kill the onion leaves prematurely, losses in yield will occur due to reduction in bulb size.

Botrytis neck rot occurs late in the season when the bulbs are close to harvest, and it can occur throughout the postharvest period. The plants often are symptomless in the field when infection occurs, with bulb rotting taking place during storage or transit. Infection is through succulent neck tissue or wounds on the onion bulb. Symptoms first appear in the neck area of the onion as a soft, semi-wet rot that eventually moves down into the bulb. The diseased onion scales appear translucent and watersoaked, with a whitish-gray fungal growth between the scales.

Disease cycle and biology. The fungus that causes leaf blight overwinters in the soil and on infected plant debris as small, dark, compact masses of fungal hyphae called sclerotia, which can survive through unfavorable environmental conditions. As conditions become favorable for disease development, fungal spores are produced and serve as the primary source of inoculum. The spores are disseminated by wind onto healthy plants in the surrounding area. For infection to occur, the *Botrytis* species that attack onions require, in general, cool temperatures of 55–75°F and prolonged periods of leaf wetness. For example, *B. squamosa* requires temperatures less than 76°F and a minimum of 6 hours of leaf wetness. If leaf wetness exceeds 24 hours, there is a likely chance that the disease will occur in the field. The amount of disease that may occur is proportional to the duration of leaf wetness. *Botrytis cinerea* requires an optimum temperature of 59°F for germination and mid-70s (°F) for fungal growth. Older leaves tend to be more susceptible to the disease than younger ones.

Botrytis neck rot is caused by *B. allii* and has a disease cycle and biology similar to the other *Botrytis* species, except that the neck rot disease can be seed-borne. The conditions that predispose onion plants to infection include moisture on the outer scales of the bulb late in the season due to irrigation or rainfall, mechanical wounds, applying nitrogen either excessively or late in the season, and harvesting prematurely while the necks are still succulent.

Disease management strategies

Cultural practices (botrytis leaf blight)

Crop rotation. Rotating onion crops for a period of at least 2–3 years with non-*Allium* species can reduce inoculum (sclerotia) buildup in the soil. The host range of

B. squamosa includes onions (*Allium cepa*), Japanese bunching onions (*A. fistulosum*, *A. boudhae*), and chives (*A. schoenoprasum*).

Sanitation. Use disease-free transplants. Remove from the field all onion plant material that may be a potential source of inoculum (cull piles, rotten bulbs, leaf debris, etc.).

Creating conditions unfavorable for the disease organism. To avoid long periods of leaf wetness when using overhead irrigation, allow for enough daylight time after irrigation for leaves to dry. Space rows approximately 12 inches apart to allow for good air circulation and leaf drying.

Chemical control (botrytis leaf blight)

Fungicides should first be applied either when five true leaves are present or when early symptoms of the disease start to develop. Spraying at 5–7 day intervals may be necessary when weather conditions are favorable for botrytis leaf blight development. Fungicides currently labeled for use in onion in Hawaii are listed in Appendix A.

Cultural practices (botrytis neck rot)

Crop rotation. Rotating for at least 2–3 years with crops that are not *Allium* species can reduce incidence of this disease. *Botrytis allii* can infect onions (*A. cepa*), garlic (*A. sativum*), shallots (*A. cepa* var. *ascalonicum*), leeks (*A. porrum*), and multiplier onions (*A. cepa* var. *aggregatum*).

Sanitation. Remove from the field all potential sources of inoculum (cull piles, plant debris, etc.).

Harvesting and postharvest handling. The keys to effective management of botrytis neck rot are curing the necks well and harvesting during dry conditions. Therefore, allow onion tops to dry down before harvesting to reduce the potential for infection. Cure onions on the ground for approximately 7–10 days if weather permits. To hasten curing, undercut bulbs at maturity to allow faster drying of the inner neck tissue. Avoid bruising and mechanical injury to the bulbs. When harvesting under wet conditions, artificial curing of onions with forced hot air (about 93°F) at 2 cubic feet per minute per cubic foot of onion bulbs will help control neck rot (see the sections below on artificial curing, p. 42, and storage, p. 43).

Storage. Store onions in well ventilated rooms at 32–33°F and 70–75% relative humidity.

Improvement of growing conditions. Avoid dense planting to allow for good air circulation. The minimum

spacing between rows should be 1 foot, with 4 inches between plants within the row. Use moderate amounts of nitrogen fertilizers. Also, avoid applying nitrogen fertilizer late in the season, which delays crop maturity and promotes large necks that are prone to botrytis neck rot infection.

Chemical control (botrytis neck rot)

Botrytis neck rot cannot be controlled with fungicides. Use treated seed to prevent field contamination. In England, Benomyl® and Thiram® seed treatments effectively control this disease.

White rot

White rot (*Sclerotium cepivorum* Berk.) is not currently found in Hawaii, but elsewhere it is considered one of the most important and destructive diseases of *Allium* species. Where it occurs, this fungus is prevalent during cool weather. Because white rot is a potential threat if it is introduced to Hawaii, the following information is provided.

Symptoms. The initial symptom is a white, fluffy mold on the stem plate extending to and around the base of the bulb. Within the white mold on the decaying tissue can be seen sand-grain sized black sclerotia (hard, dark, overwintering structures) resembling poppy seeds. Infected plants will show premature yellowing and leaf dieback, with the older leaves collapsing first.

Disease cycle and biology. *Sclerotium cepivorum* can survive in the soil for several months on infected plant debris, and its sclerotia can persist in the soil for up to 20 years. The fungus can be spread from an infected field to a clean field in water, on wind-blown infected plant material (e.g., onion scales), or by transporting infested soil on farm machinery, tools, or shoes. Germination of the sclerotia is stimulated by exudations from the roots of *Allium* species, which can affect a ½-inch zone of soil around the root. Cool (< 68°F), moist soil favors white rot development. When the temperature exceeds 80°F for several hours in a day, the fungus stops growing. The optimum soil temperature for infection is 60–65°F. When soil temperature is above 78°F, the disease spread is reduced.

Disease management strategies

Cultural practices

Avoidance. One of the most effective control measures is to avoid introducing the disease to uninfested areas.

Plant only clean plant material. Onion seeds do not normally carry sclerotia, but transplants can. Do not move culls, crop debris, or soil from infested to uninfested fields.

Sanitation. Clean equipment before moving it from an infested field to an uninfested field. Remove all onion debris from infested fields to reduce inoculum levels (number of sclerotia in the soil).

Crop rotation. To minimize disease pressure, *Allium* species should not be planted in infested fields for 4–5 years. Rotation alone will not eradicate the disease because sclerotia are able to survive for up to 20 years.

Chemical control

Soil fumigation. The use of soil fumigants such as methyl bromide may provide some control but may not be cost-effective. The use of metam sodium (Vapam®) has been shown to reduce sclerotia population levels in the soil, but control is inconsistent.

Fungicides. Fungicides applied at planting may provide marginal to adequate control (see Appendix A).

Black mold

Black mold is a postharvest fungus affecting onions during storage and transit. The fungus causing black mold, *Aspergillus niger* Tiegh, is common in areas with a warm climate and high relative humidity.

Symptoms. Initially, infected bulbs may have a black discoloration around the neck. Streaks of powdery black spores can be found between the dry, papery scales and the first fleshy scale (Figure 19, p. 30). As the disease progresses, the fungus may advance from the neck into the inner fleshy scales, and the entire bulb turns black and shrivels. The diseased bulbs may also become infected with soft rot bacteria, resulting in a mushy rot.

Disease cycle and biology. The fungus is commonly found in the soil as a saprophyte on plant debris. In warm areas, its spores can easily be found in the air and soil or on commercial seeds. Surveys conducted in New York identified high contamination levels in seed samples from both commercial and home-grown seed. The black mold fungus becomes pathogenic above 86°F and 80% relative humidity. Spores require 6–12 hours of free moisture (dew or condensation) to germinate and infect the bulb. Infection usually occurs through injured tissues at the neck, bruises in the outer scales, and wounds in the roots or basal plate. Optimum temperature for disease development ranges from 82° to 93°F.

Disease management strategies

Cultural practices

Postharvest handling. Avoid bruising bulbs during harvesting, postharvest storage, and transport. Storing onions at 35–60°F can reduce the growth of black mold. In Texas, curing bulbs at 100°F and a relative humidity below 36% has been shown to result in reduced black mold incidence.

Chemical control

In Japan, researchers reduced the incidence of post-harvest black mold by dusting the tips of cut leaves of harvested onions with calcium carbonate. Also, control of other foliar diseases reduces the incidence of black mold in storage.

Bacterial soft rot

In Hawaii, bacterial soft rots have caused significant losses of onions, especially when heavy rains occur before harvest. The disease is caused by a number of bacteria including *Erwinia carotovora*, *Pseudomonas gladioli*, and *Enterobacter cloacae*. Disease problems are observed during the preharvest and postharvest stages.

Symptoms. Initially the disease appears as a wilt, when the leaves turn white or brown, collapse, and die (Figure 20, p. 30). It progresses to the inner, fleshy bulb scales, which become soft and water-soaked. Affected tissues are initially yellow, becoming brown as the disease progresses into the bulb (Figure 21, p. 30). As the interior of the bulb starts to break down, a slimy, sour smelling liquid may ooze from the neck of the bulb when it is pressed (Figure 22, p. 30).

In Hawaii, *Xanthomonas campestris* causes leaves to have many white to yellow flecks and spots. Expansion of these spots results in leaf dieback and extensive blights of older leaves, causing stunted plants and small bulbs.

Disease cycle and biology. Soft rot inoculum survives for short periods as bacterial cells in soil or longer on infected plant debris. The inoculum is spread in water from splashing rain or irrigation and on insects and farm implements. Initial infection can occur through neck tissues of senesced leaves, but it is more commonly the result of injury caused by equipment, herbicide, bruising, rain, sun-scald, etc. Outbreaks can occur during warm, rainy periods. Decay is rapid in onion bulbs infected with the bacterium. Optimum conditions for dis-

ease development occur at 68–86°F and high humidity. If the temperature is above 37°F while the bulbs are in storage or transit, bacterial soft rot infection will continue to occur.

Disease management strategies

Cultural practices

Creating conditions unfavorable for the disease organism. Bacterial soft rot can be reduced by switching from overhead or furrow to drip irrigation when onions start to bulb. The onion bulbing growth phase occurs when the neck diameter is twice the size of the bulb. All cultural practices that reduce field moisture and prolonged periods of high humidity will decrease bacterial soft rot levels.

Harvest and postharvest handling. To reduce infection, bulbs should be harvested when leaf tops are well matured and dried. Thorough curing of the bulbs before storage is essential to prevent infection, particularly by neck and bacterial rots. It is also important to minimize injury to the bulbs during harvesting and postharvest handling. During wet periods when environmental conditions are favorable for soft rot development, onions should be artificially cured with forced hot air.

Chemical control

Bacterial soft rots cannot be controlled with pesticides, although copper fungicides (Kocide®, Champ®) may reduce infection and incidence of the disease. In Georgia, a spray mixture of copper and mancozeb is used to prevent infection of susceptible onion varieties by bacterial diseases such as *Erwinia* and *Pseudomonas*.

Nematodes

Plant-parasitic nematodes are microscopic roundworms. Many nematodes species live in the soil and infect plant tissues, usually the roots. Nematodes known to attack onions are the root-knot (*Meloidogyne hapla*, *M. incognita*, *M. javanica*, and *M. chitwoodi*), stem and bulb (*Ditylenchus dipsaci*), stubby root (*Paratrichodorus* species), and lesion nematodes (*Pratylenchus penetrans*). In the onion producing areas of California, root-knot and stem and bulb nematodes are considered serious pests and cause substantial crop losses. Other states also have reported that nematodes suppress onion growth and yield.

In Hawaii, root-knot nematode (*M. incognita* and *M. javanica*) is the only recorded serious nematode pest that periodically causes yield losses of onions. The reniform nematode *Rotylenchus reniformis* has also been reported to infect onion in Hawaii, but its effect on yield and quality is unknown.

Symptoms. Root-knot nematodes cause root swellings or galls of various sizes and shapes. The galls can be as small as $\frac{1}{25}$ inch (1 mm) in diameter. With the aid of a hand lens (at least 10x magnification), egg masses produced by female nematodes can be seen on the galls. Infected secondary root systems have abnormally small rootlets with excessive branching. Infected plants become stunted and turn yellow due to a loss in function of the root system and a resulting decline in plant vigor. In infested fields, the result of nematode infection can be observed in clumped patterns of different growth. The amount of damage that occurs to the onion crop is directly related to the size of the nematode population in the soil before planting. Due to reduced plant vigor, infected plants produce bulbs that are smaller than normal.

Plants affected by the stem and bulb nematode (also called bloat nematode) appear stunted, with leaves that are short and thick with yellow or brown spots and swollen (bloated) stems. The characteristic symptoms of this infection is the presence of plant tissues that are bloated, with a spongy appearance, and that split open. Infected seedlings are twisted, stunted, and deformed. Bulbs of older infected plants will split open or produce doubles.

Other parasitic nematodes that are not of major importance to onion production are the lesion and stubby root nematodes. The lesion nematode causes stunting of plants and irregular or elongated light to dark colored lesions on the roots. Symptoms of stubby root nematode infection are reduced plant growth and short, stubby, deformed roots.

Disease cycle and biology. Root-knot nematodes attack the roots of a very wide range of plants. This pest can survive in the soil in a dormant state or in the roots of other weed and crop hosts. The female root-knot nematode produces approximately 100–1000 eggs in its lifespan. Temperature has a tremendous influence on the length of the life cycle. For *M. incognita* and *M. javanica*, the optimum temperatures for growth and development are 77–86°F, whereas *M. hapla* flourishes at 55–77°F. When the temperature exceeds 104°F or drops below 41°F, *Meloidogyne* species are inactive. Nematodes move only several feet per season under their own power but are spread to clean fields through the movement of

infested soil in flowing water or on equipment, machinery, boots, and vegetative planting material (onion transplants and sets). Nematodes tend to be more of a problem in sandy than in clay soils. Generally, when there is less water stress on plants during the crop growing season, nematodes tend to be less of a problem.

Disease management strategies

Field evaluation. In order to make sound nematode management decisions, take soil samples before planting to determine which nematode species are infesting the soil and at what population levels. The first step in taking soil samples is to divide the field into sampling blocks determined by observed variables such as the type of crops previously grown, crop productivity, the crop to be grown, and soil type and texture. If the sampling area is uniform, then 1–20 acre blocks can be represented by a single composite sample from 15–20 subsamples of uniform size. Take the subsamples in a systematic zig-zag pattern so that the entire area is represented. Each subsample should consist of a profile of the root zone from the surface to approximately 12 inches deep. Mix the subsamples thoroughly in a clean bucket. From this mixture, take a sample of about 1 quart for analysis. Do not expose samples to excessive heat or cold; use an insulated cooler while collecting the samples. Take samples to the CTAHR Agricultural Diagnostic Service Center (ADSC) or another commercial laboratory for analysis as soon as possible. If using ADSC, samples can be sent via local CTAHR Cooperative Extension Service offices; call to determine the best time to deliver samples for prompt shipment to ADSC.

Cultural practices

Crop rotation. Grow nonhost crops for a minimum of three years between onion crops. The root-knot nematode has a very wide host range, making nonhost crop selection very difficult. Sudan grass and sorghum-Sudan grass hybrids (Sudax) are nonhosts of many root-knot nematode species and thus are suitable green manure crops in rotation with onions where *Meloidogyne* is present. Nonhosts of the stem and bulb nematodes include soybean and potato. Fallow periods may be helpful in controlling nematodes. Bare-fallow periods of three or more months are helpful in reducing nematode population levels.

Sanitation. Clean all machinery, tools, and footwear of nematode-infested soil before moving into uncontaminated fields.

Mechanical. Tillage and plowing will destroy plant roots and expose the nematodes to ultraviolet radiation and desiccation.

Resistant cultivars. No onion cultivars are currently resistant to nematode pests.

Avoidance. Plant nematode-free seeds (the stem and bulb nematode, *Ditylenchus dipsaci*, can be found on seeds). Prevent the movement of nematode-infested soil and infected seedlings or sets to uninfested areas. Infested soil can be transported in water and on machinery, tools, and footwear.

Chemical control

Soil fumigation and nematicides. Preplant soil fumigants are effective in reducing nematode population densities, but they are expensive, difficult to apply, and toxic. With the growing concern for protecting our environment from pesticide contamination, continued availability of fumigants is unlikely. Soil fumigants and nematicides currently (1999) cleared for use in Hawaii are listed in Appendix A. To obtain effective control, follow the manufacturer's recommendations given on the product label.

Weeds

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Integrated pest management (IPM) strategies can be used to manage weed competition in onion production. Like an IPM program for insects, IPM for weed control uses pest identification and monitoring, sanitation, alternative cultural practices, and timely pesticide (herbicide) applications. Making a weed map for each field helps in the design of weed control measures and provides a record of weed problems.

Cultural control practices for weeds include shallow cultivation, plowing, disking, hoeing, crop rotation, growing cover crops or living mulches, control of weed growth forced by irrigation before planting, organic or plastic mulching, and herbicide applications. Transplanting onions aids in managing weeds because it avoids two months of weed control. Proper field preparation cannot be overemphasized as a recommendation to benefit onion growth and minimize weed problems during the crop growth cycle. It is important to be aware of the weed species that are expected to flourish in a field planted to onions. Then it is possible to plan and develop a control program.

Onions are poor competitors against weeds due to their slow, vertical growth that fails to shade out weeds. Thus, early weed control is important in onion production. Plans for weed control should be made well ahead of planting, at least a year in advance. It is recommended to avoid fields with a history of high nutgrass infestation. (If nutgrass is a problem, see CTAHR publication L-9, *Nutgrass control in the lawn, landscape, and garden*.) Cultivation should be conducted carefully to prevent root damage; it may not be advisable to cultivate onion fields after the four- or five-leaf stage. Crop rotations and the use of cover crops are important tools for managing weeds as well as for breaking the life cycles of insect pests and disease pathogens.

Maintain a record of herbicide applications in onion fields. Also, have pesticide labels available to be aware of possible plant-back restrictions and potential carry-over effects on onion production. Herbicides known to have a detrimental effect on onion growth include diuron, Pursuit®, Cadre®, Zorial®, Broadstrike®, Grazon P+D®, Reflex®, Command®, and possibly Prowl® (for direct-seeding, for a 6-week period following a Prowl application).

For optimal herbicide applications use flat-fan nozzles, spray at speeds of 3–5 mph, and spray volumes of 30–70 gallons/acre (gpa) at a pressure of 20–30 pounds per square inch (psi).

A “stale seedbed” technique for planting onions may be followed. Prepare the beds at least 6 weeks before planting by cultivating lightly, then use flame or a contact (“burndown”) herbicide every two weeks to kill the flushes of weeds emerging before planting or seedling emergence. If the soil is not further disturbed, this technique can eliminate over 90 percent of the weed seeds in the surface soil layer. Follow-up controls after crop establishment may include cultivation or herbicide applications.

Refer to the pesticide label for the appropriate onion growth stages with respect to the proper timing of herbicide applications.

Before making any herbicide application, read the label to verify that its use on onions is allowed. Pesticide labels change frequently, and pesticides registered in other states may not be registered for use in Hawaii. The statements here about herbicide use and performance are for information purposes only and should not be considered as recommendations or to imply that use of the herbicides mentioned is permitted in Hawaii.

Preplanting and preemergence herbicides

Pesticides that have been used to manage weeds in onion before planting include the soil fumigant Vapam®, which is applied to well prepared, moist soil 10–14 days before planting. Vapam also provides some control of certain soil-borne diseases and nematodes. Paraquat (Gramoxone Extra®) has also been used before planting, or after planting but before onion emergence. Preemergence herbicides applied before the weeds begin to germinate, and within 3 days of transplanting, require moisture for activation. Apply 1 inch of irrigation if rainfall does not occur within 5 days of application, following a pre-emergence herbicide treatment. In New York, Buctril® applied after seeding but several days before onion emergence provided effective broadleaf control with no crop injury observed.

Postemergence herbicides

Do not apply nonionic surfactants, crop oil concentrates, or additives in combination with postemergence herbicides. These products can penetrate waxes in the onion leaves, resulting in herbicide damage.

Postemergence herbicides that have been used for onion weed control include Goal® applied on onions with two or more true leaves; Buctril applied in combination with other herbicides on onions with two or three true leaves; Prowl® (pendimethalin) used as a broadcast spray when onions have two to nine true leaves; Poast® (sethoxydim) for grass control; and Fusilade 2000® (fluazifop), which is active only on grasses and can be applied in onions with one true leaf. Fusilade treatments were more effective when grasses were in the 2–6-leaf stage and not drought stressed. Split Fusilade applications were possible as long as the total allowable volume per growing cycle was not exceeded. Research in Canada showed that Poast and Prism® worked better on large grasses with nighttime applications. Research in Michigan found purslane to be relatively tolerant of Prowl.

Research in New York indicated that a tank mix of Dual® and Goal® resulted in excellent burn-down of yellow nutsedge and other weeds and was safe on onions when Goal was applied at 1–2 oz/acre a.i. During hot weather, however, tank mixes of Goal and Buctril resulted in low levels of injury to onions.

Also in New York, postemergence Basagran® application provided good control of yellow nutsedge under high temperatures, especially after a second application, with some injury observed in onion plants. On-

ion injury with Basagran was minimal if the seedlings had at least five leaves. In addition, tank mixes of Prowl and Frontier® applied at early onion emergence did not cause injury on onion and resulted in excellent weed control.

Prism® is registered in some states for control of both annual and perennial grasses. Prism thus provides broad-spectrum grass control, and it has no rotational restrictions.

Nitrogenous fertilizers have been used effectively in the past for weed control in onions. Ammonium thio-sulfate, ammonium nitrate, and N-phuric have been used in California on broadleaf seedlings. Onion seedlings with one true leaf were not injured with the nitrogenous chemical treatments. N-phuric, which consists of urea plus sulfuric acid, at 20 gallons in 40 gallons of water per acre, gave excellent weed control. Ammonium thio-sulfate and ammonium nitrate gave good weed control at 60 gallons per acre.

Harvest and postharvest practices

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Timing

Onion maturity is reached when elongation of new leaves into the stem stops, the necks weaken, and the tops fall over. Onion crops generally are harvested when 10–20 percent of the tops have fallen over. When soil moisture is low, delaying the onion harvest after the tops have fallen may result in greater yields. In Florida, for example, greater yields were obtained in plots harvested 3 weeks past the stage when 10–20 percent of the tops had fallen over. Early harvest, before the bulbs have matured, results in less weight per bulb, higher respiration rates, and a correspondingly reduced shelf life. Delayed harvest, on the other hand, results in reduced bulb firmness and increases incidence of postharvest diseases. The time required from planting to harvest for onions in Hawaii is listed in Table 6. Onion production in greenhouses allows for precise water management and later harvesting, which maximizes yield.

Production yields

Commercial yields for the sweet bulb onions grown in Hawaii are in the range of 12,000–15,000 lb/acre (240–300 50-lb bags) with stands of 43,400–65,100 plants/acre. Bulb onion yields in other areas are 20,000–40,000 lb/acre (400–800 bags) in North Carolina; about 25,000 lb/acre in Texas; 40,000 lb/acre in Arizona; 18,000 lb/acre in Georgia; and 22,000–25,000 lb/acre in Puerto Rico with stands of 144,000 plants/acre of ‘Texas Grano 502’. “Good” yields for U.S. grown pungent or dry-type onions are 31,000 lb/acre with stands of 104,000 plants/acre. Under greenhouse conditions, yields in experimental soil beds in Volcano, Hawaii, have exceeded 2 lb/square foot of bed.

Harvesting operations

Sweet onions in Hawaii are hand harvested. Harvested onions are laid in a windrow and left for field curing.

Protection of bulbs from the sun is provided by placing the bulbs under the tops of the plants. In some cases, onions are placed on drying racks protected from rain. After the 3–5 day curing process the tops are trimmed, leaving about 3 inches above the top of the bulb, and the roots are trimmed close to the bulb. The bulbs are then loaded into a truck for transport to the cleaning, grading, and packing area.

Harvesting practices vary in other onion production areas, based on the local soil and climatic conditions. In some areas, it is recommended that onions be “lifted” about 10 days before harvest; this aids soil drying and promotes bulb maturity. Onions can be lifted with an inclined, sharp blade drawn at a moderate tractor speed or with a “rod-weeder,” which is a tractor-mounted, hydraulic motor-powered, counter-clockwise rotating square bar. To hasten bulb maturity in North Carolina, the soil is worked away from the bulbs beginning about 1 month before harvest. This process involves two or three cultivations, resulting in one-third of the bulb being exposed about 7–10 days before harvest. In some cases, a subsurface knife is used to cut the roots a few inches below the bulb to further promote bulb drying. The onions are then harvested when 75 percent of the tops have fallen over. For the harvest operation, the onions are dug mechanically or pulled by hand. Once the tops and roots have been trimmed, the onions are transported from the field within 1–2 hours and taken to cur-

Table 6. Time from planting to harvest of onions in Hawaii.

Crop	Days to harvest	
	From seed	From sets
Bulb onion	100 – 180*	70 – 120
Shallot, multiplier, and non-multiplier green onion	75 – 120	50 – 75
Futo-negi	160 – 200	

*Greenhouse-grown onions at the CTAHR Volcano Research Station (4000 ft elevation) have taken as long as 240 days from seeding to harvest. (Adapted from Fukuda 1990)

ing rooms. In Texas, bulb onions are lifted with a mechanical rod-weeder, tops and roots are trimmed with hand clippers, the bulbs are placed in bags, and the bags are left in the field for a few days to cure the onions. The onions are then loaded with a loading machine or placed by hand into trucks and transported to a packing shed. Timely removal from the field and proper curing is essential to maintain postharvest quality.

The curing process

Onions are cured to dry the neck, roots, and outer scale tissues. Effective curing results in less incidence of postharvest diseases such as neck rot, which results when botrytis and similar pathogens enter neck wounds to infect the bulb. The length of the curing process depends on field temperature, humidity, air movement, and the moisture content of the neck at topping. If the onions are harvested at a mature stage, a couple of days curing may be sufficient. In well matured bulbs, a 3–5 percent weight loss is sufficient for curing, but a weight loss of 10 percent or more may be required in less mature bulbs. The best indication of complete bulb drying is the condition of the neck. It should be tight and dry nearly to the surface of the bulb, and the outer scales should be dry and rustle when touched.

Properly cured onions have increased shelf life, but this is influenced by the particular cultivar. In Florida experiments, cured onions were held in an open barn for 3 months with little or no decay, and cured ‘Texas Grano 502’ developed only 7–10 percent decay after storage for 2 months, although ‘Yellow Granex’ developed 44 percent decay in the same treatment.

Artificial curing

It is recommended that growers have covered curing facilities to prevent bulb rotting in the field during periods of rainfall or excessive moisture at harvest and curing. Field-curing is possible only when humidity is low and no rainfall is expected. Over the past few years, onion growers on Maui and Oahu have suffered significant postharvest losses due to wet weather during the pre-harvest and field-curing stages, especially when the rainy season has extended into the spring months. Artificial curing is a standard practice in many onion producing areas of the U.S. mainland, and together with the adop-

tion of improved cultural practices (such as lower planting densities, or planting in raised beds), and other postharvest handling practices, it may improve the profitability of onion production in Hawaii.

The artificial curing process consists of exposing bulbs to ventilation (1–2 ft³/minute for every ft³ of onions) at 90–95°F and 65% relative humidity (RH) for a period of 2–4 days. RH greater than 65% is required to maintain good skin color, and RH lower than 75% is required to promote drying and prevent staining of the skin. A sling psychrometer or a hygrometer can be used to monitor RH during the curing process. Onions can be artificially cured with forced-air driers, electric infrared radiation, and solar conversion systems. Also, placing single layers of onions on elevated wire benches in a greenhouse has proven to be effective in Hawaii for curing onions.

In areas like Hawaii, where humidity can be high and unexpected rainfall is common, forced hot-air drying is an option for curing onions. In this process, matured and partially field-cured onions are placed in bins with slatted floors. Beneath the floors are ducts that allow heated air to circulate upward to uniformly dry the onions. Pallet boxes with slatted bottoms are placed over heat tunnels, so that air is forced up through the bulbs. In the southern USA, mobile trailers used for drying hay or peanuts are modified for forced hot-air curing of onions. To heat the air, commercial crop dryers are available that use propane, oil, or gas for fuel.

Grading

Buyers normally set a minimum onion size of 2 inches diameter for dry pungent onions, although some buy onions 1½ inches in diameter. Onions 3–3½ inches in diameter normally bring a premium price. Standard onion sizes are (inches in diameter) > 4 colossal, 3–4 jumbo, 2–3.5 medium, and 1–2 small. Other sizes include re-packs (1¾–3) and boilers (<2). The market for sweet onions calls for jumbo sizes, and growers often try to produce crops that are 75 percent jumbo grade.

Handling and packing

Harvest and postharvest practices should be designed to minimize the two types of physical damage that affect onions: surface injuries and bruising. Surface injuries

are caused by cuts and punctures during harvest, topping, or root-clipping. The surface cracks are penetrated by microorganisms, resulting in internal bulb decay. Bruising, induced by impact shock or vibration damage, causes cracking of the outer bulb scales. Bruising damage occurs most often when loading and unloading onion sacks. When packing lines are used in large-scale operations, areas where impact damage occurs include the unloading conveyor, loading drying bin, wire transfer belt, incline to scale brusher, incline to pregrader, incline to sizing rings, incline to labeler, and labeler to mesh bag sections.

Sweet onions in Hawaii are normally packed in 50-lb mesh bags. Fiberboard boxes provide better protection than mesh bags and are becoming more popular in the continental USA. Dry pungent onions are distributed by U.S. packers in combinations of 2-, 3-, 4-, and 10-lb consumer bags, and in 25- and 50-lb sacks. In the Imperial Valley of California, onions are also field-packed, where cured onions are sorted, sized, and packed in burlap sacks with the aid of harvest machines. For green onions, packing lines are available that can prune roots and pack at a rate of 300 boxes per hour.

Storage

Onions should be transported and stored separately from other kinds of produce, such as apples, celery, and pears, which readily absorb onion odors. Onions also can absorb odors from other commodities, such as apples. Also, well cured onions will draw moisture from nearby fresh fruits and vegetables. Because sweet onions do not store well, Hawaii onions are not normally stored for any length of time. If storage is desired, well cured onions can be stored at 32°F with a 65–70% RH. Exposure to ethylene during storage or transport may result in sprouting or growth of pathogenic fungi. Symptoms of freezing injury in onions include soft water-soaked scales and decay from microbial growth. Potential diseases of concern during storage or transport of onions include black mold, botrytis bulb rot, fusarium basal rot, and bacterial diseases (see Onion diseases, beginning on p. 28).

The development of alternative storage technologies (modified-atmosphere and controlled-atmosphere storage) may allow for the short-term storage of sweet onions, despite their limited shelf life. For example, modification of the atmosphere by lowering oxygen levels in the storage room has extended shelf life and main-

tained the quality of sweet summer onions for 3 months in storage. Similarly, use of controlled atmosphere for the Vidalia sweet onions in Georgia has allowed that industry to expand the sweet onion season, stabilize the volume of onions marketed from week to week, and increase the size of the popular Vidalia sweet onion industry. The introduction of controlled-atmosphere storage allowed many firms to double their volume of sweet onion sales. Atmospheric conditions under controlled atmosphere are kept at 3% carbon dioxide, 5% oxygen, and 70–75% RH.

Market information

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Supply

California, Texas, Colorado, Oregon, New York, and Idaho are the major states producing dry onions. From September to March, most of the dry pungent onions consumed in the USA are summer-grown storage onions. Over-supplies often occur during the spring when sales of the previous summer's storage onions overlap with new supplies from spring onion harvests. However, prices may increase in the spring if supplies of the summer-storage onions have dwindled and if spring onions are scarce. Over 38,500 acres are planted nationwide for the spring onion crop, with about 43 percent of this production in Texas. New Mexico is the largest onion supplier during the summer months, providing over 45 percent of the dry onion supply during that period.

In the world market, the Netherlands is a major onion producer, annually exporting about 500,000 tons of onions, which represents 90 percent of the onions grown there. Innovative onion marketing programs developed in the Netherlands include creation of a collective promotional institute (the NIVUI); sales under environmental-quality labels; alternative packaging such as the use of modified atmosphere packing; sales in specialized trays such as a popular mixture of two yellow, two red, and two white onions in one package; and sales of semiprocessed products. Imports of bulb onions from Latin America into the USA have risen steadily over the past decade, ranging from 99,000 tons in 1989 to over 884,000 tons in 1996, with Mexico accounting for over 90 percent of these volumes.

Important sweet onion producing areas in the USA include Georgia's Vidalia region, where the popular onions of the same name are grown in a 20-county area on about 15,000 acres harvested from mid-April to May, and Washington state's Walla Walla onions, grown on about 1000 acres. Other states producing sweet onions include Florida, North Carolina, New York, California (with over 3500 acres producing Imperial Sweets available from March to May), and Idaho (Spanish Sweets from August to March, including large, firm yellow, red, and white onions).

In 1996, Hawaii imported about 17 million pounds of bulb onions. Local production on 210 acres represented 10 percent of the bulb onions consumed locally and had a farmgate value of about \$2.4 million. Hawaii's recent production of bulb onions, consisting only of the sweet types, has ranged from 1.1 million pounds in 1990 to 2.3 million pounds in 1995.

Because Hawaii imports over 90 percent of the dry pungent onions consumed in the state, there is an opportunity to increase the acreage of pungent onion production here. However, production costs must be lowered through the use of modern technology to allow Hawaii growers to compete against the current low prices (\$5–7 per 50-lb bag) for dry onions from the continental USA.

Demand

Per-capita consumption of onions has increased steadily in the USA as consumers have learned about the health benefits of consuming fruits and vegetables, including onions. Per-capita consumption of dehydrated and fresh onions in 1970 was 10.1 lb, increasing to 12.2 lb by 1982, and again increasing to 17.9 lb by 1997. In Hawaii, per-capita consumption of fresh onions in 1985 was reportedly 14–15 lb, and this has remained constant, lagging behind the current U.S. level.

The main uses for the sweet-type onions are in salads, sandwiches, and hamburgers; in dips, garnishes, and various marinades; and prepared as onion rings and other snack foods.

Cost of production

Cost of production for sweet onions in California in 1994 was about \$1600 an acre, with water cost ranging from \$120 to \$280 an acre, depending on the snow pack for the particular season. Pre-harvest production costs for onions in Florida were estimated to represent about 64 percent of total cost, and harvesting and marketing represented about 36 percent of total production cost. Pro-

Figure 23. The farmgate price of Hawaii onions is high when supplies are low. This occurs during fall and winter, as illustrated by data for the period 1986–1996.

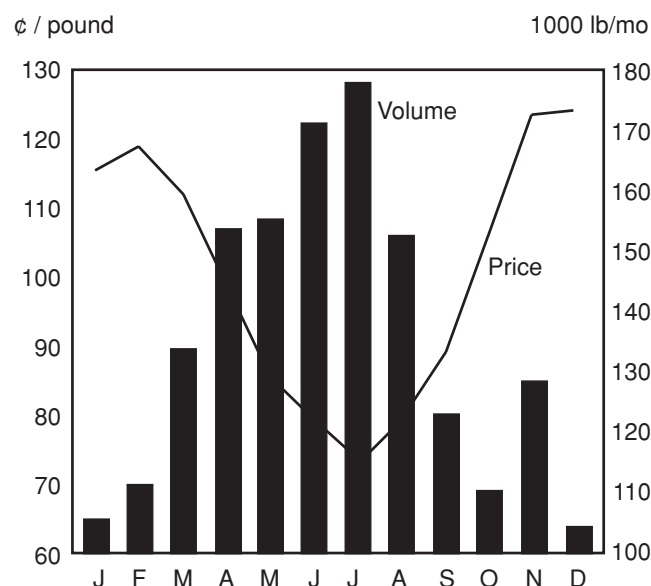
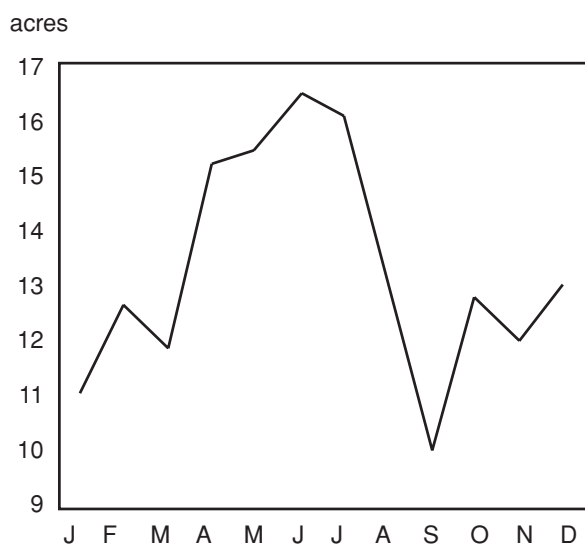
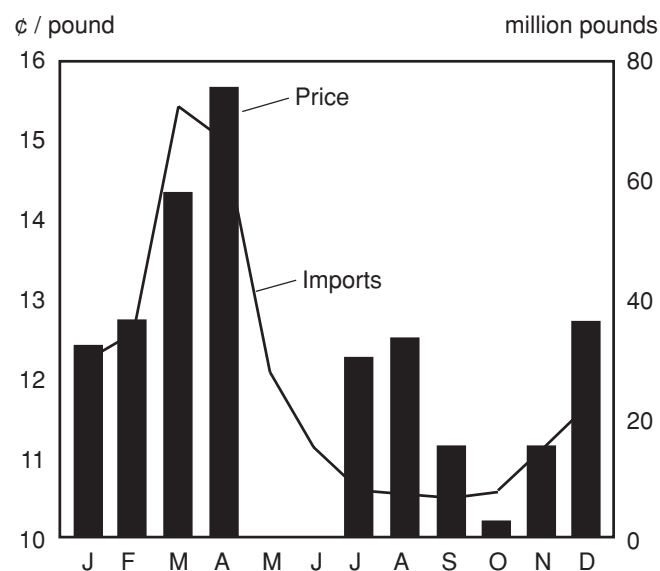


Figure 24. Monthly mean area (acres) of bulb onion production in Hawaii from 1986–1996.



duction cost per acre in 1996 for some cultural practices in Georgia included about \$200 for manual planting, \$14 for Goal® herbicide application, \$70 for hand weeding, \$600 for manual harvest, and about \$15–20 per bag for

Figure 25. Onion production and price in the USA follow a trend similar to Hawaii, but the prices are much cheaper. When supplies are low and prices are high, imports increase, as illustrated below with data from 1980 to 1993.



controlled-atmosphere storage. With Hawaii's smaller acreage, greater manual labor demands, and lack of economies of scale, Hawaii's costs are greater than production costs in the continental USA.

A sound bulb onion production program is based on well planned marketing (for additional information, see the CTAHR publication, *This Hawaii product went to market*). Prospective growers should understand annual market trends (Figures 23 to 25), market competitors, consumer needs, potential buyers, and market windows. To keep abreast of changing markets and new business opportunities, they should maintain close contact with fellow industry representatives and with business, university, Cooperative Extension Service, and government organizations.

A clear and up-to-date understanding of the farm's financial situation during the annual production cycle is essential to sound marketing. Updated financial records and the use of computer programs will help cut overhead and increase production efficiency. Updated financial information and well organized farm records are also helpful in applying for loans, assessing crop losses due to unexpected pest outbreaks, and making timely production and financial decisions to take advantage of potential investment opportunities or unexpected market windows.

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Appendix A. Pesticides for onions

The information on pesticides given here was taken from the *Crop Protection Reference Guide*, the *Pacific Northwest Disease Control Handbook*, and the *UC Onion and Garlic Pest Management Guidelines* and therefore may not be applicable to all locations. Pesticides not approved for use in Hawaii cannot be used in Hawaii. Consult the pesticide label for permitted uses, limitations, and application instructions. Read the pesticide label for the preharvest interval and do not apply within the specified number of days before harvest.

Fungicides

Downy mildew

Application of mancozeb fungicides such as Maneb® or Dithane® provides protection against downy mildew and also controls botrytis leaf blight. Application of metalaxyl and chlorothalonil provides downy mildew control for approximately 14 days. Metalaxyl should be applied on a 14-day interval; in alternate weeks, apply mancozeb or chlorothalonil to control botrytis leaf blight or purple blotch. Materials containing mancozeb should be used with a spreader-sticker. Read the pesticide label for any restrictions on nonregistered crops following metalaxyl applications.

Common name	Trade name	Amount / acre	Preharvest interval (days)
fosetyl-Al	Aliette, WDG	2–3 lb	7
metalaxyl + chlorothalonil	Ridomil/Bravo 81W	1.5–2 lb	7
metalaxyl	Ridomil MZ58	2–2.5 lb	7
metalaxyl and copper	Ridomil/Copper 70W	2 lb	10
mancozeb	Maneb 80WP	2–3 lb	7
	Dithane M45	2–3 lb	7
	Dithane F45	1.7–2.4 qt	7
chlorothalonil	Bravo Weather Stik	1.5–3 pt	7
copper	Kocide DF	2 lb	Reentry: 24 hours

Purple blotch

Spray programs for purple blotch are also effective for downy mildew control. Iprodione is particularly effective for purple blotch, but mancozeb and chlorothalonil are also effective under conditions of high disease pressure. Iprodione/mancozeb tank mixes are especially effective. Spray intervals of 5–7 days may be prescribed if leaf wetness periods exceed 11 hours.

Common name	Trade name	Amount / acre	Preharvest interval (days)
mancozeb	Maneb 80	2–3 lb	7
	Penncozeb	2–3 lb	7
vinclozolin	Ronilan DF	1.5–2 lb	18
iprodione	Rovral	1–1.5 lb	7
copper	Kocide DF	2 lb	Reentry: 24 hours
	Champ Flowable	2.67 pt	Reentry: 24 hours
chlorothalonil	(Bravo Weather Stik)	1.5–3 pt	7

Botrytis

Chlorothalonil has provided excellent control of botrytis leaf blight, but mancozeb and iprodione are also very effective. In New York, tank mixes of mancozeb and iprodione have been found effective for management of both botrytis leaf blight and purple blotch.

Common name	Trade name	Amount / acre	Preharvest interval (days)
mancozeb	Manzate 200	3 lb	7
	Dithane M-45	3 lb	7
vinclozolin	Ronilan DF	1.5–2 lb	18
iprodione	Rovral	1–1.5 lb	7
chlorothalonil	Bravo Weather Stik	1–2 pt	7

White rot (not currently found in Hawaii)

Common name	Trade name	Amount / acre
vinclozolin	Ronilan DF	1.5–2 lb

Insecticides**Onion thrips**

Common name	Trade name	Preharvest interval (days)
lambda-cyhalothrin	Warrior, Warrior T	14
cypermethrin	Ammo 2.5 EC, Ammo WSB	7
permethrin	Pounce 3.2 EC, Ambush 2 EC, Ambush 25W	1
*zeta-cypermethrin	Mustang 1.5 EW	7
malathion	Various formulations	3

Agromyzid leafminers

Parasitic wasps such as *Halticoptera circulus* keep leafminer populations in check in onion fields. Leafminer outbreaks can occur when parasite populations are reduced by frequent applications of broad-spectrum insecticides. Treat for onion thrips only when the action threshold has been reached to avoid unnecessary pesticide applications. Leafminers are difficult to control with currently registered insecticides due to resistance. Work is in progress to register effective insecticides.

Caterpillar pests (beet armyworm and Asiatic onion leafminer)

Common name	Trade name	Preharvest interval (days)
lambda-cyhalothrin	Warrior, Warrior T	14
cypermethrin	Ammo 2.5 EC, Ammo WSB	7
permethrin	Pounce 3.2 EC, Ambush 2 EC, Ambush 25W	1
zeta-cypermethrin	Mustang 1.5 EW	7
methomyl	Lannate LV, Lannate SP	7

Seedcorn maggot

Common name	Trade name	Preharvest interval (days)
diazinon	Diazinon AG500, Diazinon AG 600, Diazinon 14G	14
chlorpyrifos	Lorsban 4E, Lorsban 15G	

Herbicides

Common name	Trade name	Weeds controlled
Preplanting		
DCPA	Dacthal W-75	broadleaf weeds, grasses
glyphosate	various products	broadleaf weeds, grasses
metam sodium	Metam, Sectagon II, Soil Prep, Vapam	broadleaf weeds, grasses
paraquat	Gramoxone Extra 2.5EC	broadleaf weeds, grasses
pendimthalin	Prowl 3.3 EC	broadleaf weeds, grasses
Postplanting—before onion crop emerges		
paraquat	Gramoxone Extra 2.5EC	broadleaf weeds, grasses
pendimthalin	Pentagon DG, Prowl 3.3 EC	broadleaf weeds, grasses
Postplanting—after onion crop emerges		
bromoxynil	Buctril, Buctril 4EC, Moxy 2EC	broadleaf weeds
clethodim	Prism	grasses
fluazifop-P-butyl	Fusilade DX	grasses
oxyfluorfen	Goal 2XL	broadleaf weeds, some grasses
sethoxydim	Poast	grasses
trifluralin	various products	broadleaf weeds, grasses

Nematicides

Common name	Trade name	Amount / acre
metam sodium	Metam, Sectagon II, Soil Prep, Vapam	60–100 gal
1,3-dichloropropene 94%	Telone II	5.1–21.4 gal
1,3-dichloropropene 78.3%, chloropicrin 16.5%	Telone C-17	5.1–21.4 gal
1,3-dichloropropene 61.1%, chloropicrin 34.7%	Telone C-35	5.1–21.4 gal